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Theory of Perspective:
A continuous and sustainable internal process improvement roadmap for small business managers

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Declaration

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Abstract

Small, medium and micro enterprises are important contributors to the economic and socioeconomic development of South Africa. However, most enterprises struggle to become established. The high rate of failure is due to a lack of access to finance, poor managerial and technical skills, and also the competitive business environment.

The focus of this research report is on the development of a continuous and sustainable internal process improvement roadmap that provides skill constrained small business managers with strategic and technical support, in order to make their organisations more competitive in the current business environment, without expensive consultation.

The first step toward the development of the roadmap is discussed as a ten step basic process improvement cycle, based on an interpretation of the PDCA cycle. These ten steps provide most of the methods that are needed for practical implementation of improvement activities. However, this approach needs strategic support in order to ensure that improvement activities focus on the critical improvement opportunities.

The second step regards the identification of strategic support, and additional improvement methods, to align improvement activities toward the critical improvement opportunities, which represent a common goal. Three methodologies are discussed as individual roadmaps to determine the crucial aspects that can be integrated into a holistic management roadmap, which accommodates practical improvement. These methodologies are lean thinking, theory of constraints, and the six sigma philosophy.

The final roadmap is then developed, based on the principle that perspectives can be used to develop the perception of people toward improvement. Different perspectives are identified from the studied improvement methodologies, and the execution of improvement activities is then supported with the basic process improvement cycle.

The perspectives are categorised into three main perspectives. First, the organisational perspective provides an overview of the philosophy, people, and process. Second, the primary process perspective provides an overview of the critical process aspects; value, throughput, and quality. Third, the secondary process perspective connects these critical process aspects in terms of effectiveness, agility, and efficiency. The roadmap is then completed when management can transcend above perspective.

Opsomming

Klein, medium en mikro ondernemings is belangrike bydraers tot die ekonomiese en sosio-ekonomiese ontwikkeling van Suid-Afrika. Meeste ondernemings sukkel egter om gevestig te raak. Die hoë koers van mislukking is weens 'n gebrek aan finansiële toegang, swak bestuurs en tegniese vaardighede, en die mededingende sake-omgewing.

Die fokus van hierdie navorsingsverslag is op die onwikkeling van 'n deurlopende en volhoubare interne proses verbeterings padkaart wat klein besigheid bestuurders verskaf met strategiese en tegniese ondersteuning, sonder duur konsultasie, ten einde hul organisasies meer mededingend the maak in die huidige sake-omgewing.

Die eerste stap vir die onwikkeling van die padkaart word bespreek as 'n tien stap basiese verbetering siklus, gebaseer op 'n intrepretasie van die PDCA siklus. Hierdie stappe voorsien meeste van die metodes wat nodig is vir praktiese implementering van verbetering aktiwiteite. Die benadering moet egter strategies ondersteun word om te verseker dat verbetering aktiwiteite op die kritieke verbeterings geleenthede fokus.

Die tweede stap word bespreek vir die identifisering van strategiese ondersteuning, asook addisionele verbetering metodes, om verbetering aktiwiteite in lyn te bring met kritiese verbeterings geleenthede, wat 'n gemeenskaplike doel verteenwoordig. Drie metodieke word bespreek as individuele padkaarte om die deurslaggewende aspekte te bepaal wat geïntegreer kan word in 'n bestuurs padkaart, wat praktiese verbetering akkomodeer. Die metodieke is "lean thinking", "theory of constraints", en "six sigma".

Die finale padkaart word dan ontwikkel, gebasseer op die beginsel dat perspektiewe gebruik kan word om mense se persepsie van verbetering te ontwikkel. Verskillende perspektiewe is geïndentifiseer vanuit die verbetering metodieke, en die uitvoering van verbeterings aktiwiteite word dan ondersteun met die basiese verbeterings siklus.

Die perspektiewe is ingedeel in drie hoof perspektiewe. Eerste, die organisatoriese perspektief verskaf 'n hoë vlak oorsig van die filosofie, mense, en proses. Tweede, die primêre proses perspektief verskaf 'n oorsig van die kritiese proses aspekte; waarde, deurset, en kwaliteit. Derde, die sekondêre proses perspektief verbind die proses aspekte in terme van effektiwiteit, aanpasbaarheid, en doeltreffendheid. Die padkaart word dan eindelik voltooi wanneer die bestuur perspektief te bowe kan kom.

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1. Introduction

Small, medium and micro enterprises (SMMEs) in South Africa contribute positively to economic growth. They account for more than 95% of the formal business entities in the country and contribute between 52 to 57% to GDP [1]. These enterprises also play a significant role in socioeconomic growth with efficient and prolific job creation that provides around 61% to employment [1]. This is a crucial factor because South Africa is characterised by high unemployment levels, which are estimated at 25% [2].

Classification of the different SMMEs sizes must be understood because of their important role in economic and socioeconomic development. Enterprises in South Africa are classified according to Schedule 1 to the South African National Small Business Act of 1996, as revised by the National Small Business Act as amended in 2003 and 2004. This schedule classifies enterprises in the specific sector in which they operate based on the number of employees per enterprise in combination with their annual turnover and gross assets. A summary is provided in Table 1.1 below.

Table 1.1: SMME definitions as specified in the National Small Business Act

Enterprise size	Number of employees	Annual turnover (Less than)	Goss assets; Fixed property excluded (Less than)
Medium	Fewer than 100 or 200 dependent upon sector	R5 million to R64 million dependent upon sector	R3 million to R23 million dependent upon sector
Small	Fewer than 50	R3 million to R32 million dependent upon sector	R1 million to R6 million dependent upon sector
Very small	Fewer than 10 or 20 dependent upon sector	R500 000 to R6 million dependent upon sector	R500 000 to R2 million dependent upon sector
Micro	Fewer than 5	Less than R200 000	Less than R100 000

Source: Schedule 1 to the National Small Business Act of 1996, as revised by the National Small Business Act as amended in 2003 and 2004

South Africa has a significant level of SMME activities in comparison with similar economies; however, it is difficult to determine the exact number of enterprises in South Africa because the vast majority operates in the informal sector. The Annual Review of Small Business in South Africa provides the number of economically active enterprises of known size for 2004 and 2007. These register figures are compared by enterprise classification in order to show economic growth in the three year period. [3]

Table 1.2: Integrated enterprise register figures for 2004 and 2007

Enterprise classification	2004		2007		Growth percentage 2004 - 2007
	Count	Proportion	Count	Proportion	
Micro	212,161	49.8%	200,377	36.2%	-5.6%
Very small	170,338	40.0%	251,920	45.5%	47.9%
Small	32,397	7.6%	63,193	11.4%	95.1%
Medium	6,748	1.6%	20,750	3.8%	207.5%
Total SMME	**421,644**	**98.9%**	**536,240**	**96.9%**	**27.2%**
Large	4,596	1.1%	17,251	3.1%	275.3%
All enterprises	**426,240**	**100.0%**	**553,491**	**100.0%**	**29.9%**

Source: The Department of Trade and Industry (2008)

Table 1.2 provides two important statistics. First, SMMEs are the undisputed contributor to the total number of registered enterprises. Second, very small and small enterprises showed respectable growth while medium and large enterprises increased their numbers more than twofold. These numbers confirm the important role of SMMEs in South Africa and that their numbers continue to grow in general.

To further appreciate SMMEs it is crucial to understand their life cycle. Note that the terms enterprise, organisation, and business are interchanged throughout this report.

1.1 The enterprise life cycle methodology

The enterprise life cycle methodology (ELCM) is a set of phases that represent the lifespan of an enterprise through different periods. Its purpose is to ensure that the right set of tools is used to support the enterprise. However, the business needs of the enterprise must drive system development and associated technologies, and not the other way around. The ELCM also supports performance evaluation of business measures to determine to what extent the goals of the organisation are achieved. [4]

The ELCM is represented through six sequential phases: (1) analysis and strategy, (2) concurrent enterprise planning and enterprise engineering, (3) project execution, (4) operations, (5) evaluation, and (6) decommission. Continuous improvement is recurrent and supports operations based on the evaluation. The enterprise advances through these phases in accordance with specific criteria defined by each phase. [4]

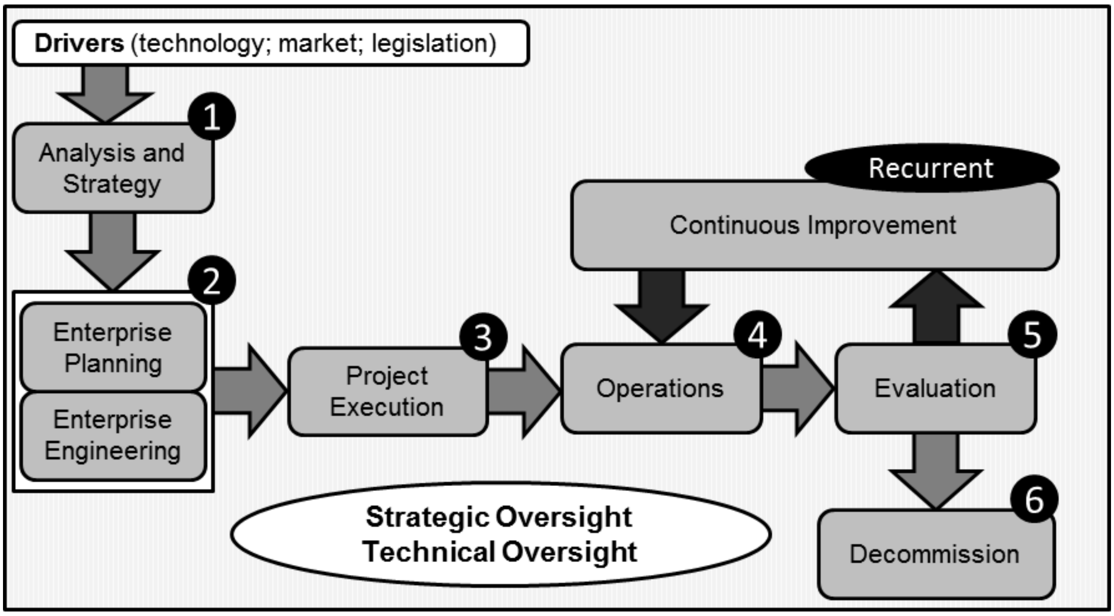


Figure 1.1: The enterprise life cycle

The first phase, *analysis and strategy*, is initiated by one or more of three external drivers: (1) technology, (2) legislation, and (3) the market. These drivers initiate the business idea and are analysed together with other external forces to further develop the idea into viable enterprise opportunities. Furthermore, the vision and mission statements of the enterprise are defined to determine the strategic business goals.

The second phase, *enterprise engineering and enterprise planning*, is characterised by innovation to determine optimum business functions and processes that must be in place to ensure value creation. It also includes the specification of products and services that will be delivered, the potential market, and ownership of the enterprise.

The third phase, *project execution*, involves the initiation of business functions and processes. A schedule is developed to transform the business plan into an enterprise that can start with business and perform operations that are aligned with the goals and strategies. This relies on synchronised implementation to integrate procedures.

The fourth phase, *operations*, includes all the processes that are required to fulfil the business objectives. These can be divided into three categories: (1) core processes, (2) supporting processes, and (3) management processes. The profitability of the enterprise relies on the successful implementation and execution of these processes.

The fifth phase, *evaluation*, involves measurement activities for performance analysis to determine if processes are still aligned with the enterprise strategies. Evaluation is therefore crucial for survival because it is used to identify problems and improvement opportunities that can be exploited in the continuous improvement phase. However, evaluation can also determine that the enterprise should rather be decommissioned.

The recurrent phase, *continuous improvement*, strives to perfect current processes through implementation of improvement solutions in the operations phase. These solutions are based on the data that was analysed in the evaluation phase. Various improvement methodologies can be used in order to increase the competitive strategy of the enterprise; these improvement methodologies inspired the focus of this report.

The final phase, *decommission*, is the point where the enterprise is retired because of one or more factors. Internal factors include a lack of direction because of a drift in focus, conflict between management priorities, or political infighting. External factors include new and aggressive competitors that are more successful in the same market space, customer satisfaction which has declined to such a level that rectification will be nearly impossible, as well as changes in the same drivers that initiated the ELCM.

The strategic and technical oversights provide guidance and support for successful business operations. These oversights include various improvement principles and strategies, as well as statistical analysis and process optimisation tools. The execution of these oversights requires integration of operations with a problem solving culture that strives to ensure compliance, integration and cohesion of operational activities.

1.2 Problem statement

Small enterprises often struggle to survive and achieve financial success in South Africa. This statement is supported by the fact that 75% of new enterprises do not become established firms. The high rate of enterprise failure is due to various internal and external factors that can be grouped into three categories: (1) access to finance, (2) managerial and technical skills, and (3) the competitive business environment. [5]

The lack of *access to finance* is of critical importance because it restricts SMMEs to achieve their full potential. Finance is required to hire external consultants and also for the acquisition of new and advanced business technologies. This is a fundamental constraint for entrepreneurs who want to expand their businesses in South Africa. [6]

Poor *managerial and technical skills* render management incapable to recognise poor work methods, and thus oblivious to the need for improvement. A large segment of SMMEs in South Africa also suffers from shortages of tools and methods required to proactively adapt to business changes [7]. These shortages are due to a lack of adequate training and education, as well as insufficient management experience. [8]

The current *competitive environment* increases pressure to improve quality and also to reduce cost while processes remain flexible and objectives are achieved; in South Africa the economy is governed by large enterprises that have first-hand information on market movements and business opportunities. These enterprises can afford the latest technologies that give them full knowledge sharing capabilities. SMMEs do not have the same infrastructure and struggle to survive because they have to compete with established large international enterprises in the same business environment. [5]

1.3 Goal and objectives

The goal of this research report is to develop a systematic and proactive roadmap that provides skill constrained small business managers with basic directions toward sustainable and internal process improvement, without expensive external consultation.

Two objectives have been identified that must be accomplished in order to achieve the goal: strategic support and technical support. These objectives were derived from the oversights that provide guidance within the ELCM, to support the roadmap in terms of skill requirements. The achievement of these objectives is crucial to ensure compliance, integration and cohesion of the roadmap for holistic improvement.

Strategic support provides a framework of principles and strategies for management, in order to drive and promote improvement initiatives. This includes the development of an improvement culture that solves problems, exploits opportunities, and strives to achieve process perfection. The affected stakeholder must therefore recognise why, how, and when improvement opportunities should be implemented and maintained.

Technical support provides the statistical analysis and process optimisation tools required to execute the strategic support. These tools must be relatively easy to understand in order to enable people with no or little previous process improvement experience to successfully use them. Furthermore, technical support should not replace strategic and tactical thinking, but rather support it where applicable.

1.4 Research approach

This research report starts with a discussion of a ten step basic improvement cycle, based on an interpretation of the PDCA cycle, which provides the technical support for the roadmap. Then the roadmap is aligned toward continuous improvement with the addition of focused management aspects, which are derived from three common process improvement methodologies: (1) lean thinking, (2) theory of constraints, and (3) six sigma. These methodologies were selected because of their potential relation to the project performance triangle in terms of process value, throughput and quality.

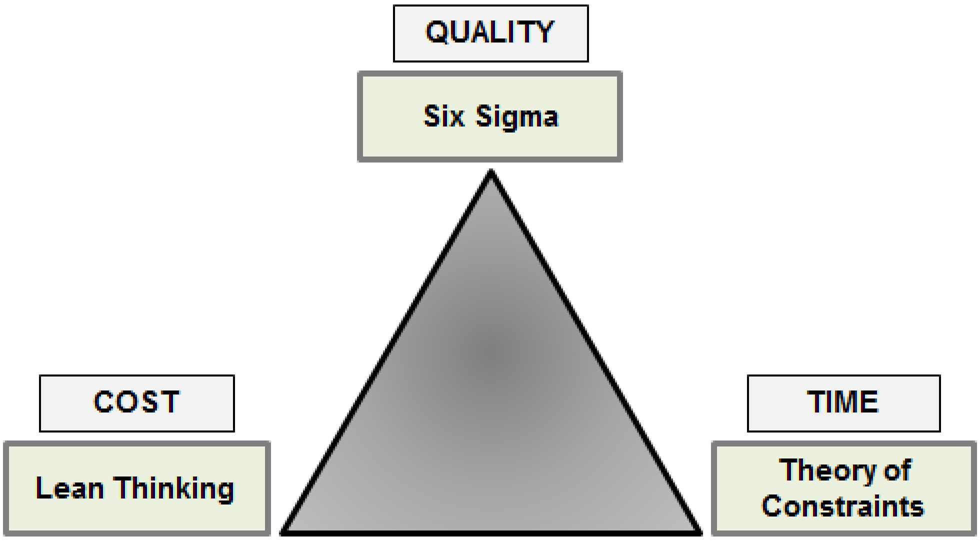


Figure 1.2: Improvement methodologies vs. project performance triangle

The first methodology, lean thinking, is discussed from a cost perspective in terms of value creation. The purpose is to understand the principles and techniques behind the philosophy that states value must be increased faster than cost is accumulated.

The second methodology, theory of constraints, is discussed from a time perspective in terms of throughput. The focus is on a strategic and a tactical roadmap that aim to increase system throughput with the alleviation of the current system constraint. Both these roadmaps are supported with an independent throughput accounting approach.

The third methodology, six sigma, is discussed from a quality perspective. Various process optimisation and basic statistical analysis tools are explored in context of the DMAIC cycle. The purpose is to understand the development of a quality conscious culture and systematically deal with the elimination of variation and process defects.

These methodologies form the core of the literature study. They consist of various tools, which are discussed where most appropriate and in the context of the specific philosophy on which each methodology is based. These tools are discussed in short, even though some of them seem rather straightforward, in order to ensure that the technical aspects are understood, implemented and aligned with the strategic aspects.

The systematic approach followed to complete the literature study resulted in a set of independent roadmaps. The next step was the integration of these roadmaps into a single combined roadmap that makes the improvement philosophies accessible to skill constrained small business managers, without expensive consultation. A strategic framework was developed to guide a continuous improvement culture toward process perfection with the support of basic statistical analysis and process optimisation tools.

2. Basic Process Improvement

Modern process improvement concepts can be traced back to initiatives undertaken in companies in the 1800s when management implemented incentive programs to promote employee driven improvement activities. Then Frederic W. Taylor published "The Principles of Scientific Management" in 1911. This introduced time studies that analyse process steps to determine the best way to do them, design specialised equipment, educate expert workers, and set production standards. Two years later Henry Ford implemented these principles to create flow and increase throughput. [9]

Walter Shewart first introduced the idea of cyclical improvement in 1939; before than improvement was implemented as a sequential approach. This concept evolved into what became known as the Shewart cycle. W. Edwards Deming modified this concept in order to develop the Deming wheel, which he presented in 1950 during an eight-day seminar in Japan sponsored by the Japanese Union of Scientist and Engineers. The Japanese adopted this approach and recast it as the PDCA cycle. [10]

The PDCA cycle is a four phase approach used to solve problems with the careful planning and small scale implementation of solutions, which is then analysed with feedback measures to identify and standardise the most successful solutions. This approach combines various resources in a concerted effort to achieve improvement.

Plan phase: This initiation phase determines what should be done, who should do it, when should it be done, and where it should be done. This includes the identification of a focus area and the selection of a team, which is required to identify opportunities and problems, generate and evaluate solutions, and develop the improvement plan.

Do phase: The purpose of this phase is to implement a pilot improvement process on small scale basis and support it with data collection. Data is first collected to create a baseline that enables the team to track improvement efforts. The data is then used to evaluate predicted results and also to identify and analyse unexpected occurrences.

Check phase: This phase is also called the *study phase* to emphasise the extensive analysis of the data collected in the previous phase. The goal is to extract and derive new knowledge with basic data analysis tools and improvement reviews. Data is also evaluated to ensure that results are in line with organisational objectives and policies.

Act phase: This phase reflects on the information from the check phase to determine what improvement solutions to adapt when needed or to adopt as the standard mode of operation. Otherwise, the changes are rejected and new alternatives are evaluated for implementation. Nevertheless, the cycle is repeated for continuous improvement.

These four phases are simplified into ten steps to create a management framework that guides a problem solving culture with incremental directions toward improvement without the support of external consultation. This cycle also provides the practical implementation roadmap to align activities with various improvement methodologies.

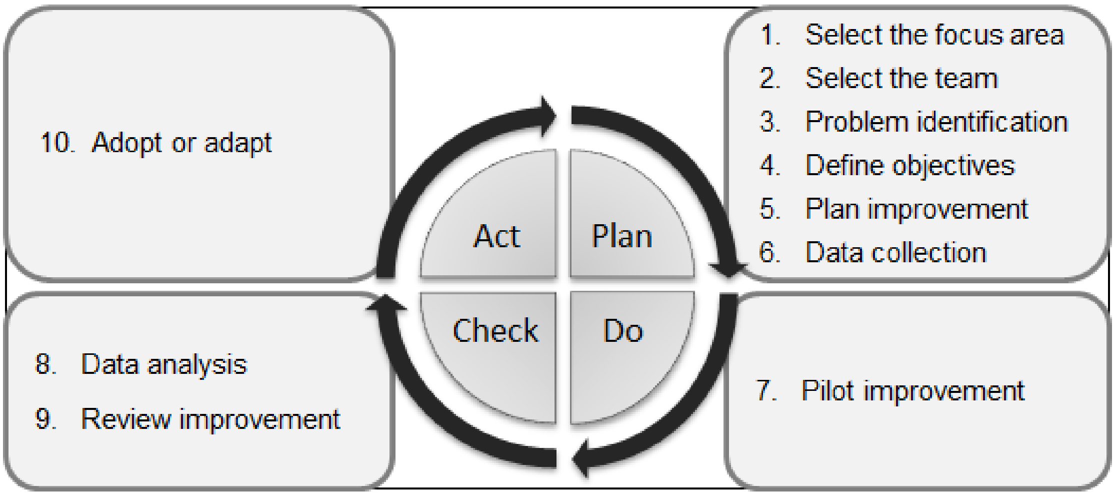


Figure 2.1: Basic process improvement steps based on the PDCA cycle

2.1 Select the focus area

The first step is to identify potential focus areas appropriate for improvement. Noriaki Kano [11] suggested that a focus area can be identified from two main sources that also initiate the need for transformation; either a problem exists (crisis), or an opportunity exists (vision). Whatever the source for improvement, three steps guide the selection process: (1) process selection model, (2) impact analysis matrix, and (3) boundaries.

Step 1: Process selection model

The selection of the focus area is crucial when several opportunities for improvement are available; higher consideration in improvement selection leads to better results in a shorter time. The process selection model provides a basic approach to optimise the selection process through the categorisation of potential focus areas in terms of how complex the focus area is and also the impact that improvement will have on the performance of the entire organisation. This model is represented in Figure 2.2. [12]

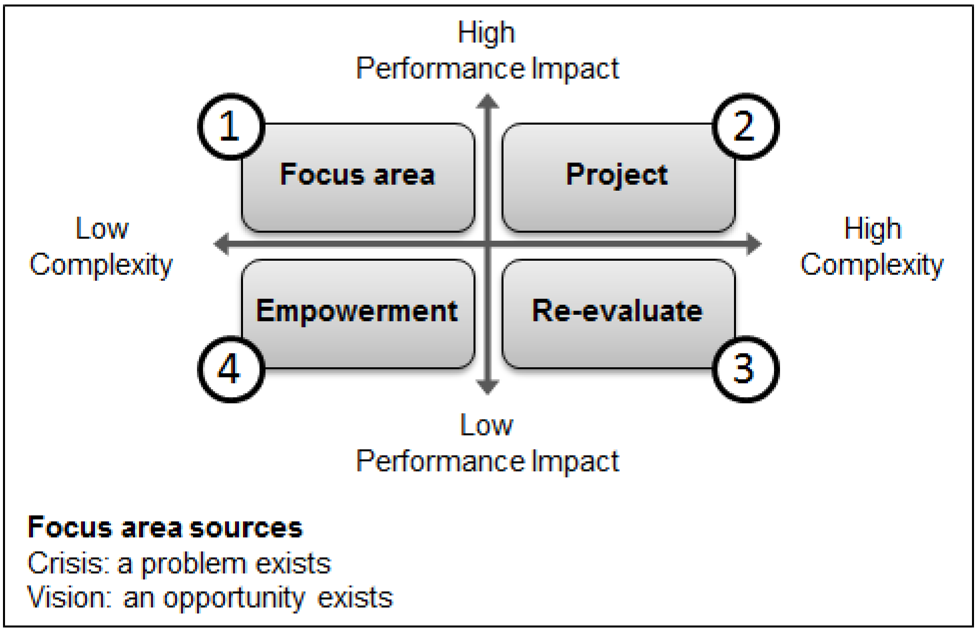


Figure 2.2: Process selection model

1. *Focus area*. This is the recommended area to start with improvement because it provides the largest gain with the least amount of effort, which means that improvement opportunities must be easy to exploit, yet have a large impact on process performance. These opportunities often include observable and physical waste in the process, and only need basic tools to capture measures.

2. *Project*. These improvement opportunities are important because of their high impact on process performance. However, these are difficult to implement and often need a project-orientated approach to ensure success. This means that improvement activities need a large investment in people and resources.

3. *Re-evaluate*. The improvement opportunities that fall into this quadrant should be reconsidered to determine if the effort is worth the gain. This area includes complex problems with a low impact on the performance of the organisation.

4. *Empowerment*. These daily management opportunities provide employees with the responsibility to use personal judgment to make decisions within the context of best practice methods. This approach requires an environment of complete cooperation where employees are thoroughly trained and educated to deal with these easy to implement, low impact improvement opportunities.

Step 2: Impact analysis matrix

The impact analysis matrix follows an analytical approach to prioritise tasks. This is a valued tool when it is difficult to select the most suitable focus area with intuition from a list with several potential opportunities. The matrix is used to rank the impact of all the improvement opportunities with reference to specified evaluation criteria. [13]

Evaluation can be based on various criterion such as compliance to business goals, customer satisfaction, data availability, and financial prospective. A weight is then assigned to each criterion, which represents their relative importance to achieve the objectives. Sum the product of the impact weights and importance weights for each opportunity. The opportunity with the highest total is considered the most important.

Scale:
3 = High; 2 = Reasonable; 1 = Low; 0 = None

Weighted Impact Evaluation	**Evaluation Criteria**				
	Business objectives	Customer satisfaction	Information availability	Financial prospective	**Total**
Importance	**3**	**3**	**1**	**2**	
Opportunity one	2	2	2	1	**16**
Opportunity two	3	1	1	0	**13**
Opportunity three	3	2	2	1	**19**

With this scale *Opportunity three* is the most important: 19 = (3x3) + (3x2) + (1x2) + (2x1)

Figure 2.3: Impact analysis matrix

Step 3: Boundaries

Boundaries are used to establish process ownership and determine how the process interacts with other processes. This is important to determine who are included in the studied process on a functional and cross-functional level. Boundaries also support team selection to ensure that the relevant people participate in improvement activities.

When the most important improvement opportunity is identified it should be selected as the focus area. Then the boundaries can be identified and describe in the required detail; first define the start and end points, and then define the rest of the process boundaries. Boundaries that are too wide can suffocate available resources, but if they are too narrow the process is suboptimised and problems can arise elsewhere.

2.2 Select the team

The improvement team is a group of people that work toward a common goal. Their purpose is to plan, implement, monitor, analyse, and evaluate process improvement activities. The team should combine their knowledge, experience and expertise in order to execute and manage improvement activities throughout the organisation. [14]

To initiate a team, members from top management select a leader based on personal characteristics, behavioural skills and technical skills. This person must be respected by both management and workers. Enough resources must then be allocated to train and educate the leader in terms of how to lead, coordinate, and organise a team. [15]

Team members are selected on the recommendation of the leader. Resources must also be allocated to educate them in appropriate theory and practice. A diversity of knowledge is helpful, but it is not necessary to have all affected areas represented on the team. However, the members must transcend above the boundaries of their own functional areas to create a cross-functional team. They should understand that they represent the welfare of the organisation, and not just their own interest groups. [15]

A typical team would consist of between five and nine people, but it depends on the focus area. The team should include the supervisor or shop floor leader, people that are affected by the process, and relevant support from people in human resources, administration, finance, logistics, maintenance, engineering, and quality control. [14]

2.3 Problem identification

The first team activity is the identification of problems related to the focus area. Many logical and visual problem identification tools can be utilised to document the process and identify root causes, in order to help the team understand the process so that improvement is focused on the significant opportunities. Note that this chapter does not distinguish between problems and opportunities because both are approached with the same improvement steps, and the terms are therefore often interchanged.

Three problem identification tools are discussed in this section. All of them require only observational information and systematic thinking to predict what changes can cause improvement. Their respective uses are to document the process, organise possible causes that can lead to a specific outcome, and question the rationale behind assumptions. These tools are flowcharts, cause-and-effect diagrams, and five whys.

2.3.1 Flowchart

The flowchart is a basic mapping tool that provides a visual summary of the flow and decisions that compose the current state of the studied process. This helps people to understand, define, document, study, improve, or innovate material and information flow within a process. Flowcharts also provide effective communication between process participants, clarify roles and responsibilities, and describe interactions. [15]

The objective of a specific flowchart determines the level of detail required. This can be one of three levels: (1) macro, (2) mini, and (3) micro. Macro level maps are used in the initial cycle to depict the process in fewer than six steps and it also provides a basis for further refinement. Mini level maps document one step as identified in the macro level flowchart, but the finer detail is omitted. Micro level maps document each action and decision to show detailed information on how operations are executed. [16]

Before the team starts to develop the flowchart they must review three important elements. First, ensure the boundaries are defined to determine the start and end points of the flowchart. Second, determine the level of detail needed to understand the process. Third, consult the process owner for input; this person should already be part of the improvement team. Once this is done the flowchart can be developed. [17]

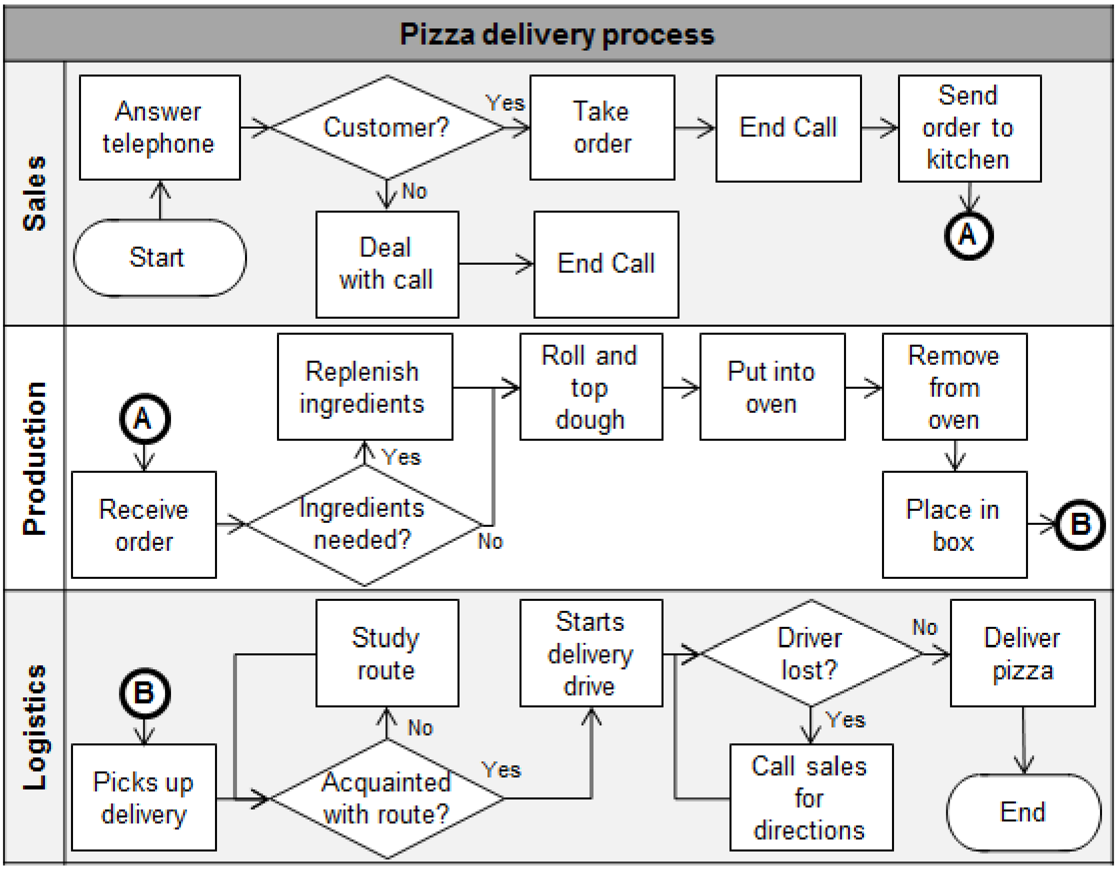
Step 1: Observe the current process and choose an object to follow. The object will depend on the process and the purpose of analysis, but it can be a person, piece of material, or paper form. Information can also be mapped but it is often tough to track; the easiest approach is therefore to follow a physical object throughout the process.

Step 2: Record the observed process steps. These steps must be recorded in the actual sequence as observed, and not prescribe how the work should rather be performed. Write these steps on individual index cards and paste them on a chart with swim lanes; swim lanes are used for the visual representation of functional responsibilities and also to visualise the cross-functional complexity of the process.

Step 3: Write a brief, yet detailed description of what has happened. Add measures such as cycle time and travel distance if it provides information relevant for possible improvement. Furthermore, interview the people that do the work, and also examine desk procedures, work flow diagrams, and other documents that describe the process.

Step 4: Summarise and evaluate the data. Create a summary block that provides the total number of operations, transportations, delays, storages, and inspections. Also determine the cycle time, travel distance, and other relevant measures. Then consult the process owner and process standards to determine if the flowchart is accurate.

Step 5: Analyse the flowchart; the important process information is now available to be queried. Evaluate each process step and decide if it can be eliminated, reduced, combined, rearranged, or simplified. When the flowchart display a clear picture with good process flow, a lower level flowchart can be created that provide more detail.



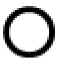
Symbol	Description
	Indicates the start and end points of the process
	Represents an individual step or operation in the process
	Represents a decision point
	Indicates a step is connected to another page or part of the flowchart

Figure 2.4: Basic flowchart with swim lanes

2.3.2 Cause-and-effect diagram

The cause-and-effect diagram was developed in 1943 by Dr. Kaoru Ishikawa, when he realised that people are often overwhelmed by the large number of factors that can influence a process. He therefore developed this simple tool to represent the assumed relations between potential causes and a desired outcome of the process.

People often refer to this diagram as the fishbone diagram because it resembles the head and bones of a fish. The fishbone structure provides a systematic approach that encourages team based analysis to discover, organise, and summarise knowledge about potential causes. The steps to construct this diagram are discussed below. [12]

Step 1: Identify and define the outcome, known as the effect, then write it in the box on the right side of the diagram. The effect can either be positive (desired outcome), or negative (problem). Select a positive effect to encourage pride and ownership of the process; negative effects should be avoided to prevent “finger pointing”. Positive effects also encourage a positive approach to generate more creative solutions. [15]

Step 2: List the main causes that can influence the effect. These provide the general structure of the diagram. Sometimes various potential causes are identified before the main causes can be isolated. Therefore, it is common to use the 6M causes to create the general structure. These are management (policies), manpower (people), methods (procedures), materials, machines, and milieu (general environment). [18]

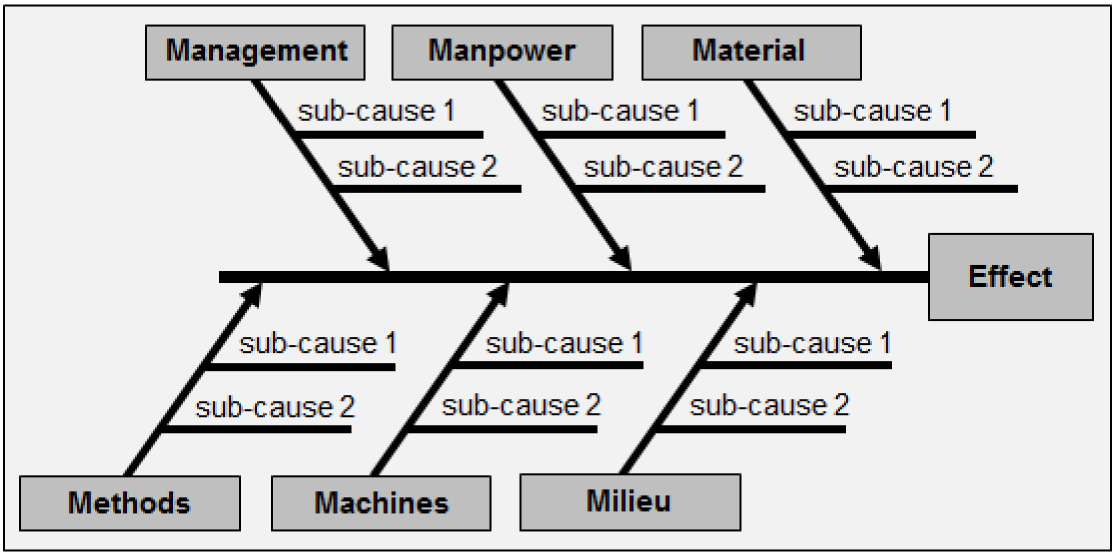


Figure 2.5: Cause-and-effect diagram (fishbone diagram)

Step 3: Continue to search for more potential causes and categorise them under the appropriate main causes. Various basic idea generation techniques can be used to identify these sub-causes. An effective approach is to brainstorm for causes, prepare cards for each identified sub-cause, and then categorise these cards in consensus.

Step 4: Isolate the sub-causes that can be considered the root causes of the studied effect. First, look for sub-causes that appear more than once and list them. Second, evaluate the rest of the sub-causes and add those with high potential to influence the effect. Third, use an idea prioritisation technique to rank them in order of significance.

Step 5: Evaluate the list of significant causes identified in the previous step. Collect more data to determine if the most significant cause has a notable impact on the studied effect. If this is not the case the team should continue to evaluate the next most significant cause to determine if it has a notable impact. Note that each cause can be used as the subject (effect) in a lower level diagram for further analysis. [15]

2.3.3 Five whys

Five whys is a simple but effective technique that is used to question and evaluate assumptions. Often, potential causes suggested by people are actual symptoms and not root causes. Five whys is then used to question the suggested causes up until the root cause is identified or the questions do not yield any more useful information. [19]

Problem:
The product is not completed

1. Why is the product not completed?
    - The production machine is broken
2. Why is the machine broken?
    - The motor seized
3. Why did the motor seize?
    - The motor wasn't maintained
4. Why wasn't the motor maintained?
    - Nobody knows how to maintain the motor
5. Why doesn't anybody know how to maintain the motor?
    - Nobody is trained to maintain the motor

Solution:
Train operators to maintain the motor

Figure 2.6: Five whys

Five whys is often used in conjunction with the cause-and-effect diagram. The idea is to question the identified causes for further analysis. Although this approach provide logical evidence that a cause is significant it is still necessary to verify this statement with analytical tools that uses actual data to support the hypothesised influences. [15]

Often people attempt to force the five whys into exactly five steps, but five is only a proposed number used to avoid a premature conclusion. Therefore, continue to follow what appears to be obvious links in the process to avoid preconceived ideas. Also, when a problem has many possible causes it is crucial to isolate and pursue the most significant cause, or else five whys will become tedious and consume too much time.

2.4 Define objectives

At this point in the improvement cycle each team member must fully understand the critical aspects of the studied process. Members must therefore be able to develop realistic goals and objectives for the focus area. Furthermore, the cause-and-effect diagram and flowchart should show a clear representation of the studied process.

Process owners are responsible to achieve objectives that have a direct influence on their processes. The affected people must also understand the objectives and devote their efforts toward the achievement the objectives. This means that participants must share the same purpose, which drives pride and ownership of individual operations.

Clear formulation of objectives is crucial to communicate the improvement purpose; many initiatives fail due to vague descriptions of expectations. Ambiguous objectives can be avoided with a pragmatic view of success and the use of SMART, which represents specific, measurable, achievable, relevant, and time bound objectives. [20]

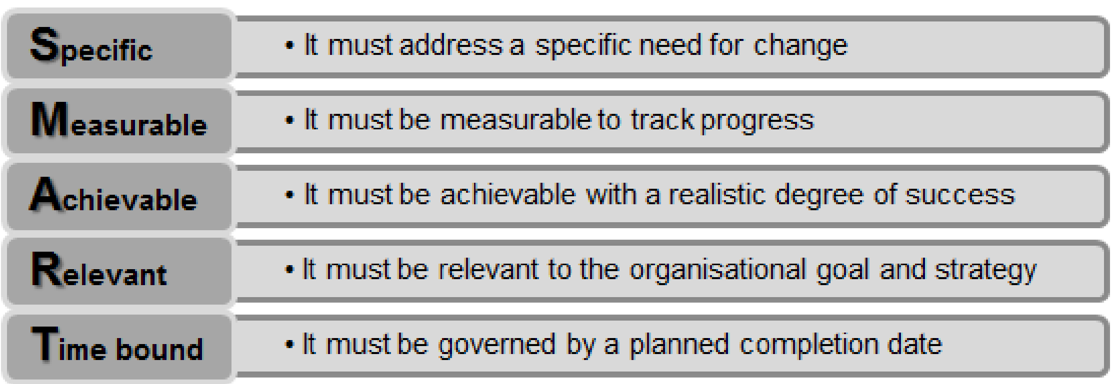


Figure 2.7: Criteria for a SMART objective

2.5 Plan improvement

The entire improvement team should be included in the improvement plan to exploit their knowledge and experience. This requires a structured approach to generate and prioritise ideas in order of significance. The most significant idea is then evaluated for further refinement. Note that the term "idea" is used because the same approach that is discussed here to generate solutions can also be used in the problem identification phase for the identification and prioritisation of root causes to process problems. [15]

2.5.1 Idea generation

The purpose of idea generation is to come up with as many as possible ideas that can be implemented to eliminate problems or to exploit opportunities. This approach also encourages team participation to increase the knowledge base that contributes to the idea generation process. The first step is to brainstorm and identify potential ideas, and then use an affinity diagram to organise mutual ideas into categories. [12]

Step 1: Brainstorming

Brainstorming is a systematic, team based approach used by teams to generate a large number of ideas in a quick session with maximum team input. This requires participation from each team member to foster a sense of ownership in the studied topic as well as the accompanied activities. Also, team members that make direct contributions to the course of a decision are more likely to ensure that it is sustained.

There are several rules that contribute to successful brainstorming. First, provide an environment free of discussion, including criticism and compliments, for unrestricted exploration of ideas. Second, do not hesitate to suggest absurd ideas, because they may lead to creative thinking. Third, do not allow one or two people to dominate the brainstorming session. Fourth, remove all interruptions that might interfere with the session or cause distractions. Fifth, arrange team members in a circle or U-shape to promote the free flow of ideas. Once these are understood the session can start. [21]

Step 1: Start with a clear definition of the problem statement and the objectives. State the topic to be discussed in the form of a question and ensure that each participant understand the process and improvement expectations. Then post the topic on a flip chart or similar device; ensure that the topic is posted where everyone can see it and refer to it throughout the session. This helps to maintain the focus on the right ideas.

Step 2: Decide what format will be used to perform the session. Select one or more of these three idea generation formats: (1) structured, (2) unstructured, and (3) silent.

Structured, one-at-a-time, brainstorming is established by rotation and offers each person an equal opportunity to contribute one idea per turn, regardless of status or personality. Any individual who is not ready with an idea when his or her turn comes can pass until the next round. A complete round of passes ends the session. This type of brainstorming lacks spontaneity and can sometimes feel rigid and restrictive.

Unstructured brainstorming requires team members to call out ideas as they come to mind. The advantage of free-form brainstorming is that participants can build off each other's ideas in a relaxed environment, but less assertive or lower status participant may not contribute. It is therefore crucial that the facilitator enforces ground rules and monitors the session to ensure that participants have equal opportunity to contribute.

Silent, write-it-down, brainstorming requires participants to individually write ideas in private on paper to be collected and posted for other members to see. This prevents a team from being influenced by a single participant or common flow of ideas; but then again, the group loses the synergy and spontaneity that comes from an open session. Silent brainstorming is therefore best used in conjunction with other formats.

Step 3: Set a time limit for the session. A good start is 10 minutes, which can later be extended by five minute intervals if ideas are still being generated; remember that brainstorming is the rapid generation of ideas, so less time can be better. Assign a timekeeper and data recorder. Then review the rules even if the team already knows them because participant often violate the rules and start to judge each other's ideas.

Step 4: Record ideas on a chart as they are called out, or collect ideas written by team members. Write down the ideas exactly as presented by the team member to avoid judgment and misinterpretation. Try to generate as long a list as possible and encourage people to think "outside the box". Display the ideas where everyone can see them so that participants can build on each other's ideas and avoid duplication.

Step 5: Clarify each idea with the help of the contributor to ensure that all participants understand it in the same way. The session ends after each participant is given a final opportunity to add ideas. Then proceed to organise the ideas with an affinity diagram.

Step 2: Affinity diagram

The affinity diagram, develop by Japanese anthropologist Kawakita Jiro, is used to organise and consolidate large amounts of qualitative data into groups based on their natural affiliation. This data can consist of ideas, opinions, issues, and facts, which are frequently the result of a brainstorming session. Additional data sources include customer and employee surveys, complaints, suggestions, and benchmark data. [22]

Affinity diagrams encourage a new pattern of thinking that gets people to work on a creative level while they address difficult issues. This is particularly effective when problems or objectives have not responded to traditional or well established thinking patterns. It is also useful when the team have incomplete knowledge of the studied process, or when individuals with diverse experience and expertise form a new team.

As a rule of thumb, it is not necessary to use an affinity diagram if less than 15 ideas have been identified; instead, the team can begin with one of the idea prioritisation techniques to isolate the most significant solutions for implementation. Otherwise, the steps below can be followed to create an affinity diagram that organise the collected data into clusters, which represent the latent structure of the opportunity under study.

Step 1: Present the ideas generated through brainstorming and other means. Write down the ideas on cards and post them on a table in a random manner within reach of each member. Make sure that members have the same interpretation of the ideas.

Step 2: Let the team members physically move the cards that seem related together in a group off to the side without talking. Then look for ideas that are related to those that have been already set aside and add them to that group. Thereafter, look for other ideas that are related to each other and establish new groups. Team members are allowed to move the cards at will. This means that one member may move a card to one group, and another member may move the card back to its former group.

The process is repeated until the team has moved all the cards into groups. Cards that don't fit into any group shouldn't be forced into a group. Let them stand alone or create a miscellaneous group. Furthermore, if consensus cannot be reached, make a duplicate of the card and place one copy in each group. Don't continue with this for too long, if too few piles remain it may hide the latent structure of the opportunity. [15]

Step 3: Create header cards that capture the fundamental theme between the ideas contained in a group of cards; the group facilitator prepares the header cards. Each card must consist of a phrase or sentence that clearly conveys the meaning. Try to use action sentences to describe a practical theme. Do this step together, out loud.

Try to find cards that already exist within each group to serve as potential headers and place them at the top of the group of related cards. Alternatively, discuss and agree on the wording of cards created specifically to be headers. Then try to group the header cards under even broader groups (super headers). Continue to group the cards until the definition of a group becomes too broad to have a clear connotation. It is recommended to limit the total number of groups to between three and fifteen. [15]

Step 4: Document the completed affinity diagram. Start with a problem statement or opportunity at the top of the diagram. Then place header and super header cards above the groups of ideas. Draw circles around the groups for distinction between themes. Also, draw lines that connect the super headers and sub headers to end up with a hierarchical, graphical structure that represents the relations between groups.

Step 5: Determine which of the identified areas should be considered for more detailed analysis; the headers present the critical areas, while the categorised ideas represent the potential improvement opportunities within the critical areas. The next step is the identification of the most significant idea with the use of idea prioritisation techniques.

Note that affinity diagrams follow an inverse approach from the one used to create a cause-and-effect diagram. The latter start with major causes as headers and then identify various lower level causes to categorise under these headers; however, affinity diagrams begin with lower level ideas and then organise them under headers.

2.5.2 Idea prioritisation

When a range of alternative ideas has been created the trouble is to select the most feasible one for implementation. Choices can be made by guesswork, by intuition, by experience or by arbitrary decision. However, it is better if an idea can be selected through means of some rational procedure [23]. Any one of the following three tools can be used for a systematic approach to support team based idea evaluation and prioritisation: (1) multi-voting, (2) nominal group technique, and (3) pairwise ranking.

Option 1: Multi-voting

Multi-voting provides a quick and easy way to reduce an extensive list of ideas to a manageable smaller number of ideas. It relies on group decision making to identify what is important to the team, with limited discussion. This tool is best suited for large teams and long lists. The execution of multi-voting is discussed in the following steps.

Step 1: Work from a large list of ideas developed by means of brainstorming or from groups organised by an affinity diagram. Ensure that each idea is clearly understood by all participants. Then assign a letter to each idea to speed up the voting process.

Step 2: The voting starts with each team member selecting the most important one-third (or no more than one-half) of the ideas, which they believe have high priority, by listing the letters that appear next to those ideas. Voting may be done either by the show of hands or by paper ballot when the team chooses to preserve confidentiality.

Step 3: Compile the votes and place a checkmark next to each item for each vote it received. Retain the ideas with the most votes and continue with the next round of voting. A rule of thumb to determine which ideas should be eliminated after each round depends on the size of the group. This simple rule is displayed in Table 2.1. [24]

Table 2.1: Number of ideas to eliminate with reference to team size

Number of team members	Number of votes for elimination
Five or fewer	Two or fewer
Six to fifteen	Three or fewer
Fifteen or more	Four or fewer

Step 4: Repeat the process and continue to eliminate ideas until the top four to six ideas are established. The ideas that were not identified as current priorities should be retained as backup for potential future use by the team in improvement activities.

Step 5: The process is finalised when the team has selected a potential idea for pilot implementation. However, if one idea cannot be isolated for selection, the process can be repeated with fewer votes allowed for each person. Nonetheless, use force field analysis on one or more of the top ideas to further refine the selection process.

Option 2: Nominal group technique

Nominal group technique is a weighted ranking method that is utilised to prioritise a large number of ideas. This approach provides a structure that gives everyone an equal voice with limited interaction between team members, which helps to avoid individual domination. The execution of this selection technique is discussed next. [25]

Step 1: Work from a large list of ideas developed by means of brainstorming or from groups organised by an affinity diagram. Ensure that each idea is clearly understood by all participants. Then assign a letter to each idea to speed up the voting process.

Step 2: Each team member writes down the letters designated for each idea. Then they assign each idea a numerical value based on their own judgment of what they consider priority. The highest number is assigned to the most important idea and the lowest to the least important idea. For instance, if there are five ideas lettered A to E, the highest priority idea is assigned a 5 and the lowest priority idea is assigned a 1.

Step 3: Rankings are collected and the facilitator transcribes each number next to the corresponding idea on a chart pack. The idea with the highest point total is the one of most importance to the whole team. Then the facilitator rewrites the list of ideas in order of their importance. In the end, the team performs a quick check to ensure that prioritisation makes sense and isolate the highest priority idea for force field analysis.

Option 3: Pairwise Ranking

Pairwise ranking is a team based method used to prioritise a list of ideas. This tool is most effective when used to rank a short list in a rational manner. It requires the team to compare items by ranking each of them against the other. The combined results of these paired rankings are used to prioritise ideas. This method is discussed below.

Step 1: Work from a short list of ideas developed by means of brainstorming or from groups organised by an affinity diagram. Ensure that every idea on the list is clearly understood. Assign a letter to each idea and construct a matrix with the ideas shown at the top and to the left so that each cell represents an intersection of two ideas. [26]

Step 2: Determine which idea is preferred for each intersection by show of hands or by paper ballot when the team chooses to preserve confidentiality. Write the letter of the preferred idea in the appropriate cell. Repeat this process until the matrix is filled.

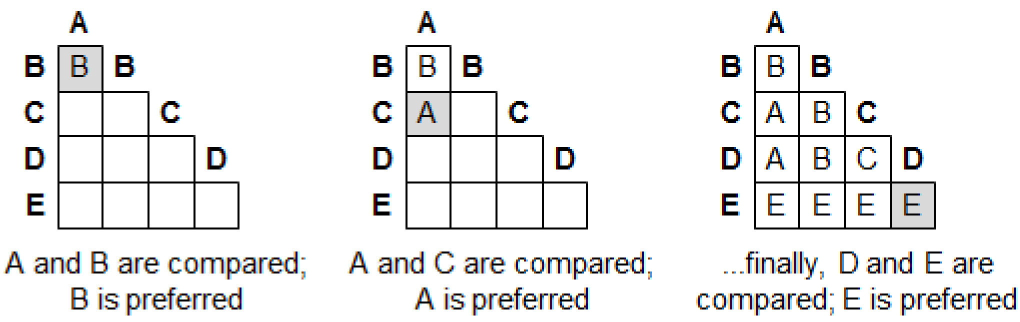


Figure 2.8: Pairwise ranking matrix for five ideas

Step 3: Rank the ideas by the number of times they appear in the matrix. The idea with the highest overall ranking is considered for implementation after a force field analysis. However, if two ideas appear the same number of times, look at the cell in which these two ideas were compared to determine which idea received preference.

2.5.3 Force field analysis

Force field analysis was created by social psychologist Kurt Lewin in 1943 [27]. This tool is used to analyse the forces for and against the change. Its purpose is to decide whether to go ahead with an idea, and to respectively strengthen forces that drive an idea and weaken forces that restrict an idea. This helps the team to understand the requirements for successful execution so that their focus is on the critical elements.

A force field analysis session should be supplemented with a fair amount of debate and discussion that deal with concerns, problems, and solutions. These can include various forces such as people, resources, behaviours, regulations, values, needs and desires. The five steps below help to manage improvement with the identification of forces that must be addressed and monitored for successful idea implementation. [28]

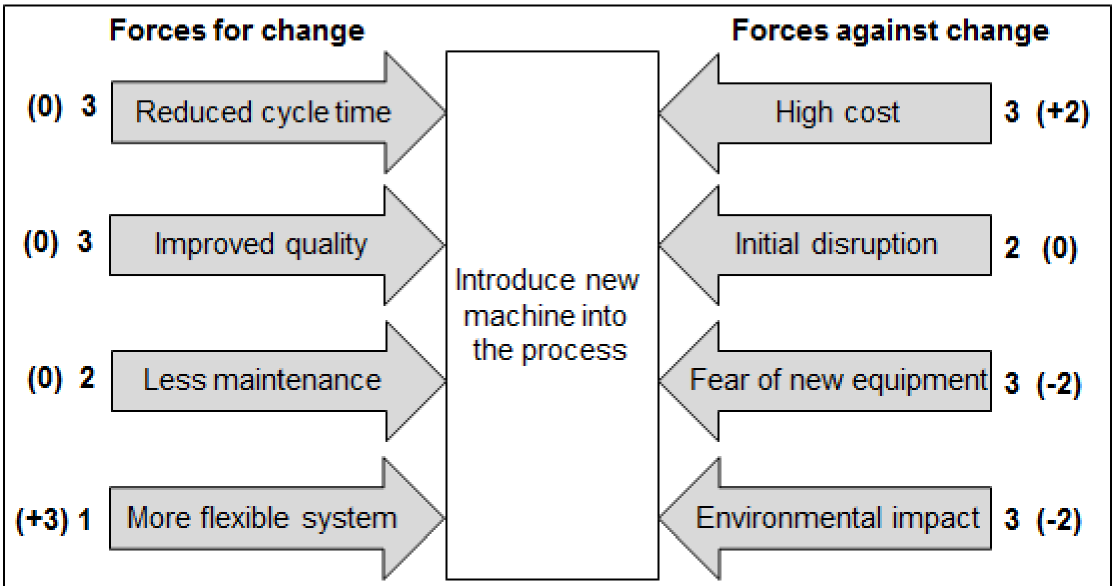
Step 1: Ensure that the team understands the nature of the current situation and why improvement is needed. Furthermore, explain the desired future state that is expected from the implementation of the analysed idea. Define this state as clearly as possible.

Step 2: First, brainstorm the main forces that would support change in the desired direction. Second, brainstorm forces that would resist the proposed change. Place these respective forces on the left and right side of the force field analysis diagram, visualised as labelled arrows. Third, discuss the relationships between these drivers.

Step 3: Assign a number from 1 (weak) to 5 (strong) to represent the relative strength of each force. Then rank the respective forces from strongest to weakest and add the scores to compare the total value of forces for change versus forces against change.

Step 4: The team can use the current results to decide whether or not to continue with an improvement idea. They can also think about how to strengthen the forces that support the idea and weaken the forces that restrict the idea. These changes can swing the balance in favour of an improvement idea if it was previously opposed.

Step 5: Verify the forces and use the balance ratio as a guideline to determine if an idea is viable for implementation. If the idea is viable continue to manage the forces to ensure successful implementation. However, if the idea is not viable because of some uncontrollable forces, repeat the force field analysis with the next priority idea.



Balance before suggestions: **9:11** (Against the idea)

Suggestions to strengthen/weaken forces	**Affected Force**	**Effect**
Train staff to reduce fear of new equipment	Cost	+1
	Fear of new equipment	-2
Integrate machine with other processes	More flexible system	+3
Install filters that will reduce pollution	Cost	+1
	Environmental impact	-2

Balance after suggestions: **12:9** (In favour of the idea)

Figure 2.9: Force field analyses

2.6 Data collection

Data collection is crucial for all the process improvement activities. First, it creates a baseline so that improvement activities can be monitored and tracked to ensure that it doesn't create new problems. Second, the data collected is reviewed and analysed to determine if the process is stable and reliable enough to support future decisions.

Even when some of the required data is already available, emphasis should be put on new data to ensure that the data is applicable to the current situation. However, new data can sometimes be difficult to collect; the team should therefore create a data collection plan with operational definitions. They may also need to create data collection forms to standardised methods that support continuous data collection. [29]

2.6.1 Operational definitions

An operational definition is a clear and concise definition of a measure. The definition is used to ensure that everyone in the system understands and collects data in the same manner. This also supports clear communication to avoid misinterpretations that can add variation to measurements. Therefore, it is important to develop operational definitions at the start of improvement activities to ensure consistent data collection.

An effective operational definition has three elements: (1) a criterion that provides a standard against which to evaluate the measure, (2) a procedure to test the measure, and (3) a decision as to whether test results show the measure meets the criterion. [15]

Operational Definition	Forklift loads truck in time
Criterion	The complete process from the point that the forklift enters the warehouse until it exists again must be less than 30 minutes
Test	The time to load the truck is measured with a calibrated stopwatch as the process is performed from start to end
Decision	If the truck is loaded no more than 30 minutes after forklift enters the warehouse and exits it again, the criterion is met. In other words, the forklift loaded the truck in time.

Figure 2.10: Operational definition

2.6.2 Data collection plan

Data collection is a common weakness of process improvement teams [12]. A data collection plan is therefore needed to ensure meaningful and valid data is collected right the first time. The steps below are used to develop a plan that communicates the requirements for appropriate data collection. However, the level of thoroughness and plan formalisation is determined by the complexity of the process measures.

Step 1: Determine the data to be collected with specified operational definitions. Data can be categorised into two groups: Attribute data and variable data. Attribute data is based on the occurrence of discrete events such as number of defects; and variable data are based on continuous characteristics such as time, length, temperature, and weight. The team should always try to collect variable data because it requires fewer data points for statistical analysis and also enables the quantification of variation. [15]

Step 2: Determine the data source and location where the data will be collected. The team must focus on the location of the activities that produce the significant process characteristics. These characteristics can be derived from the problem and objectives.

Step 3: Determine who will collect the data. Process workers have the best chance to collect data because they are closest to the required data. They also know the process best and can easily detect when problems occur. However, data collectors must be trained in data collection procedures. The team should also be involved to ensure efficient procedures and that anomalies or problems are recorded and corrected. [12]

Step 4: Determine when the data will be collected and the number of data points required. Enough data must be collected to make a statistical determination, but the team must also consider what amount is practical. They should therefore attempt to collect enough data in a specific time when the data is available. It is preferred that each characteristic is measured on a continuous basis, but this isn't always practical.

Step 5: Determine how the data will be recorded. First think how the data will be analysed and displayed. This helps the team to plan data collection in a format that supports analysis and display. The team can then design and test data collection forms to create standardised methods for defect free and efficient collection methods.

2.6.3 Data collection forms

Manual data collection is often required by teams; even automated processes do not always have automated data collection procedures. So the team needs to develop forms to meet manual data collection requirements. This should include the people that are assigned to collect the data to ensure clear and simple forms are developed.

Data collection forms have three important uses. First, it is used to record data on the process characteristics identified for analysis. Second, it provides a historical record of a process over time. Third, it simplifies the data collection for people who are not familiar or comfortable with collection procedures as a regular part of their job. This section discusses two types of data collection forms: check sheets and rating scales.

Check sheets

Check sheets are structured forms that enable the collection and organisation of data with minimum effort. These forms are used to capture quantitative or qualitative data in real time at the location where the data is generated. Then the collected data can be analysed and converted into useful information for detailed process assessment.

Three types of check sheets, subjected to the process, are used in practice: tabular, location, and graphic. Tabular check sheets are easy to use because the collector simply makes a checkmark in a column to indicate the presence of a characteristic or records a measurement value. Location check sheets visualise the exact physical location of a specific characteristic. Graphic check sheets are designed to collect and display data together, or in time, because data is recorded onto a graph-like chart. [30]

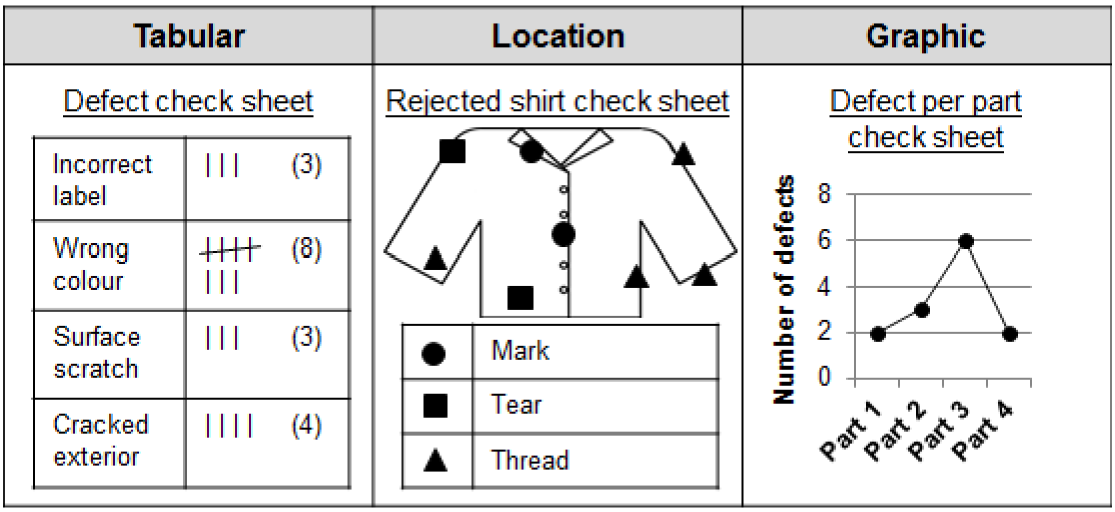


Figure 2.11: Different types of check sheets

Note that the examples in Figure 2.11 are for illustrative purpose only and that they still lack a lot of detail. An effective check sheet should provide information about the circumstances that can influence the collected data. Furthermore, it should include the name of the data collector, the date and time, and space to write comments in case of unusual events. It can also include brief instructions on the back of the form.

Rating scales

Rating scales are useful when quantitative data is not available or when it is difficult to acquire; for example, it can be used for surveys where attitudes or satisfaction are measured. However, rating scales treat qualitative data as quantitative data to enable statistical analysis. Various types of rating scales can be used for data collection, but this report focuses on qualitative description rating scales for process improvement.

Qualitative description rating scales are particularly useful to analyse a process when numerical data are not available or sufficient. The typical format consists out of five or ten levels that are arranged in hierarchical order with operations definitions. A scale is used by an observer to rate a process with reference to one of the available levels.

Table 2.2: Rating scale

A clean and organised workstation	Description
Level 1	• Cigarette butts, scraps of paper, and tools are scattered around the floor
Level 2	• Clutter is found by the walls • The passageways are not clear
Level 3	• Tools are disorganised in the storage areas
Level 4	• Machinery and equipment are clean • Items are clearly labelled • Necessary items are aligned to a grid
Level 5	• There is constant and continual cleaning from wall to wall • The area is clean, and the tools are laid out separately

2.7 Pilot improvement

The improvement plan that was developed should be explored and refined through pilot improvement. A common mistake is to skip initial improvement and go straight to full scale implementation. This can cause improvement activities to fail and can create problems. Therefore, pilot improvement is vital to avoid premature conclusions.

Pilot improvement provides various insights into the process. First, dependencies in the components of the system are identified. Second, the temporal effect of change becomes transparent. Third, the relationship between prediction and actual system performance is determined. Fourth, appropriate actions to deal with variation are identified. Fifth, changes in social behaviour of employees are better understood. [31]

Pilot improvement should be designed so that as few resources as possible are invested, while at the same time enough is learned to move towards full scale implementation. Remember that the practical consequence is that some tests are expected to fail, but this is not a problem if the team learn from those failures. The next three principles help to minimise risks associated with pilot improvement. [32]

Principle 1: Keep pilot improvement as small as possible at first and then increase the scale based on the amount and type of knowledge acquired. Solutions developed in a conference room do not always perform as predicted. Small scale change is therefore required to provide an evaluation of the impact and side effects. However, small scale does not mean small change; rather, the test is tried with one person, for a short time period, or with one component (such as a new tool) of the process.

Principle 2: Introduce different conditions as the scope is expanded. Even if changes were successful it may not work when implemented because some circumstances have changed. Therefore all circumstances that could affect the process should be discussed and plans to evaluate their impact should be included in initial tests. These include season change, new employees, demand variation, and new technology.

Principle 3: Use data collection to monitor implementation. The team must define and document the objectives of pilot improvement, and assign roles and responsibilities to each participant. This must include a data collection plan to monitor execution and ensure that the activities are carried out as planned. The collected data also sets the foundation for future evaluation and statistical analysis to assess improvement results.

2.8 Data analysis

The main purpose of data analysis is to convert raw data into useful information. The information is then used to decide if the improvement objectives have been achieved within specification limits. Data analysis is also used to learn more about the process and the new information can be used to recognise further improvement opportunities.

Histograms and run charts are common data analysis tools. A histogram analyses the process at a specific moment, while a run chart displays process performance over time. Simply put, a histogram is like a snapshot of the process, while a run chart is like a movie of process performance. These tools are developed from a statistical foundation. The team should therefore understand the basics of numerical analysis.

2.8.1 Numerical analysis

Each of the statistical analysis tools discussed in this report is developed from basic numerical analysis. There are three important data characteristics that the team must understand for the utilisation of statistical tools: (1) the location or centre of the data, (2) the spread or variability of the data, and (3) the shape of the data distribution. [33]

The *location or centre* of the data provides information about the behaviour of the typical value of a characteristic of the data. Measures that are used to summarise central tendency of the data include the process mean, the median, and the mode.

The arithmetic mean, or average, is the most common numerical representation of the typical value of the data; it is calculated as the sum of the data divided by the count of data items examined. The median is given by the middle value, or arithmetic mean of two middle values, when the data is arranged in order from small to large; it is not influenced by the magnitude of outliers as is the mean. The mode is the value that occurs most frequently; it is also not influenced by the magnitude of outliers.

The *spread or variability* of the data refers to how the data is dispersed around the mean. Variation is inherent to processes and this should be quantified to establish a predictable process. Variability is calculated as the range or the standard deviation.

The range is the most basic measure of process variability. It is simply calculated as the difference between the largest data point and the smallest data point. The larger the range, the more dispersed the data; a smaller ranges means less dispersed data.

The standard deviation considers each data point and their distances from the mean to measure variability in a dataset. Notice the population and the sample standard deviations are calculated slightly different, this is shown in Figure 2.12 below. Also note that a larger standard deviation translates into higher variation in a distribution. [15]

The *shape* of a data distribution can be measured by skewness, or lack of symmetry, and kurtosis. These calculations are not discussed in this report because data that is represented in graphical form provides the shape of the distribution at a glance; so rather focus on graphical analysis because it is easier to interpret for non-specialists.

Population			
Sample A		**Sample B**	
1	6	5	5
4	1	1	5
6	5	5	4
6	4	9	4
1	1	5	2

Measures of central tendency

Mean: $\bar{x} = \frac{\sum x}{number\ of\ items} = \frac{1+4+6+6+1+6+1+5+4+1}{10} = \mathbf{3.5}$ (Sample A)

$\mu = \frac{\sum x}{number\ of\ items} = \mathbf{4}$ (Population)

Median: $\overleftarrow{1\ 1\ 1\ 1}\ \boxed{4\ 4}\ \overrightarrow{5\ 6\ 6\ 6}$ $M_e = \frac{4+4}{2} = \mathbf{4}$ (Sample A)

Mode: $\mathbf{1}$ (highest frequency) (Sample A)

Measures of variation

Range: $R = x_{max} - x_{min} = 6 - 1 = \mathbf{5}$ (Sample A)

Standard deviation: $s = \sqrt{\frac{\sum(x - sample\ mean)^2}{number\ of\ items - 1}} = \mathbf{2.27}$ (Sample A)

$\sigma = \sqrt{\frac{\sum(x - population\ mean)^2}{Number\ of\ items}} = \mathbf{2.14}$ (Population)

Figure 2.12: Numerical analysis

2.8.2 Histogram

A histogram is a data analysis tool that is used to summarise a large set of variable data in a graphical format for ease of interpretation. This tool summarises information in terms of location, spread, and shape of the distribution. The first step is to develop a relative frequency distribution and then organised the information in a column chart.

A single histogram does not evaluate the process through time nor does it determine if the process was stable when the data was collected. It is therefore crucial to use the most recent data available for analysis. Once at least 50 to 100 data points have been collected, as suggested by mathematicians, a histogram can be developed. [15]

Step 1: Define the intervals for the frequency distribution. The number of intervals is calculated as the square root of the number of data points. Then divide the range of the dataset by the number of intervals to calculate the width of each interval. Finally, determine the starting point for each interval. Use the smallest value in the dataset as the starting point of the first interval. The starting point for the second interval is the sum of the smallest data point and the interval width. Continue this for each interval.

Step 2: Determine the frequency distribution of the dataset. Start to arrange the data points from smallest to largest. Then count the number of data points that fall within each interval to determine the data frequencies; count the data points that are equal to or greater than the starting value and less than the ending value of each interval.

Step 3: Prepare the histogram. First, label the horizontal axis with the intervals that were used to create the frequency distribution. Second, label the left axis with the relevant frequencies. Then finish preparation of the chart with a descriptive header, the name of the process and data collector, and the time and date of data collection.

Step 4: Plot the data on the prepared graph to show a clear picture of the frequency distribution. Draw a column for each interval to visualise the distribution of data. The columns have two important characteristics: height and width. The height represents the number of times a data point is counted in an interval (the frequency); the width represents the size of each interval, this is the same for all intervals. Check that the plotted histogram represents a reasonable and logical picture of the process within specified limits. Remember that this analysis is only valid for a specific point in time.

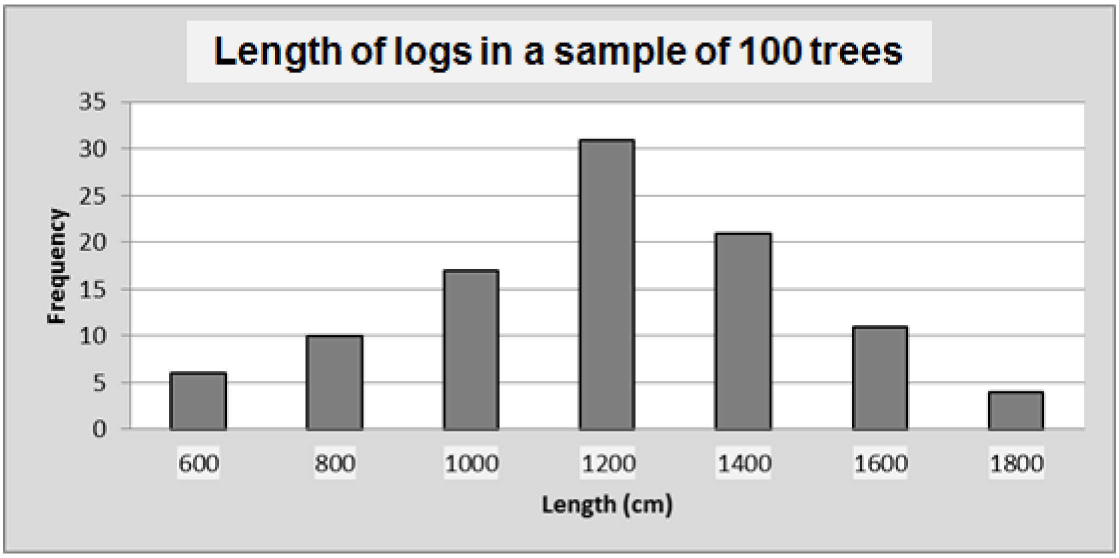


Figure 2.13: Histogram

Step 5: The histogram can now be used for the interpretation of the location, spread, and shape of the dataset. Remember that variation can occur so the histogram won't be in perfect symmetrical shape. The histogram may also have more than one peak, be discontinued, or be skewed. Either way, the team must continue with analysis to determine if there is an actual problem before they jump to premature conclusions.

Note that the histogram discussed in this section focuses on the use of variable data because it is more efficient in general. Nevertheless, almost the same procedure can be followed with attribute data; however, the column width doesn't represent an entire interval when attribute data is used, but each column represents one attribute.

2.8.3 Run chart

A run chart is a basic tool that represents process performance over time in the form of a chronological line graph. It is used to analyse data that was collected over an appropriate number of time periods. The purpose is to assess and achieve a stable process through the recognition of process performance patterns. These patterns are the result of special causes of variation, which are events external to the system. [34]

The relative ease of development and interpretation of a run chart makes it a widely used tool and one of the most popular methods to identify, analyse, communicate, and understand process variation. This approach is explained in the next five steps.

Step 1: Prepare the data. Ensure that a suitable amount of sequential data points are available for analysis. Then arrange the data from smallest to largest and calculate the range. This already provides some insight into the variation within the process.

Step 2: Determine the median of the dataset. The median as used as the centreline, instead of the mean, to neutralise the effect of very large or very small values. Note that the difference between the mean and median becomes smaller as the process stabilise, therefore, the mean can also be used as an critical performance indicator.

Step 3: Prepare the chart. First, construct the vertical axis 1.5 to 2 times the range with the median at the centre; this axis shows the magnitude of the data. Second, construct the horizontal axis 2 to 3 times as long as the vertical axis is tall; this axis represents the sequence in which the events of the process occurred. Third, finish preparation of the chart with a descriptive title and legend to ensure clarity of data.

Step 4: Plot the data points in the sequence that they occurred in. Look for outliers to identify the first signs of special cause variation; outliers are points that occur beyond the expected process limits. Once all the data points are plotted, connect them with straight lines in order to make further analysis easier and to complete the run chart.

Step 5: Interpret the run chart. Identifiable patterns can occur as a consequence of the presence of special cause variation. Three main types of patterns indicate the existence of this unwanted process variation: (1) trends, (2) runs, and (3) cycles. [15]

A *trend* is the gradual increase or decrease in the level of performance. It is depicted by five or more consecutive data point all going up or all going down. If two or more consecutive points are the same, one point can be ignored. The causes of trends are factors that change progressively, such as temperature, tool wear, maintenance, costs, and fatigue. Even though trends are often easy to detect, novice practitioners sometimes see trends that do not exist; thus, take care to avoid premature decisions.

A *run* signals a special cause of variation when eight or more consecutive points are on one side of the centreline. Points that touch the centreline are ignored but when a point crosses the line the run is stopped and a new one starts. Runs can be caused by broken equipment, calibration issues, setup errors, and other cumulative factors.

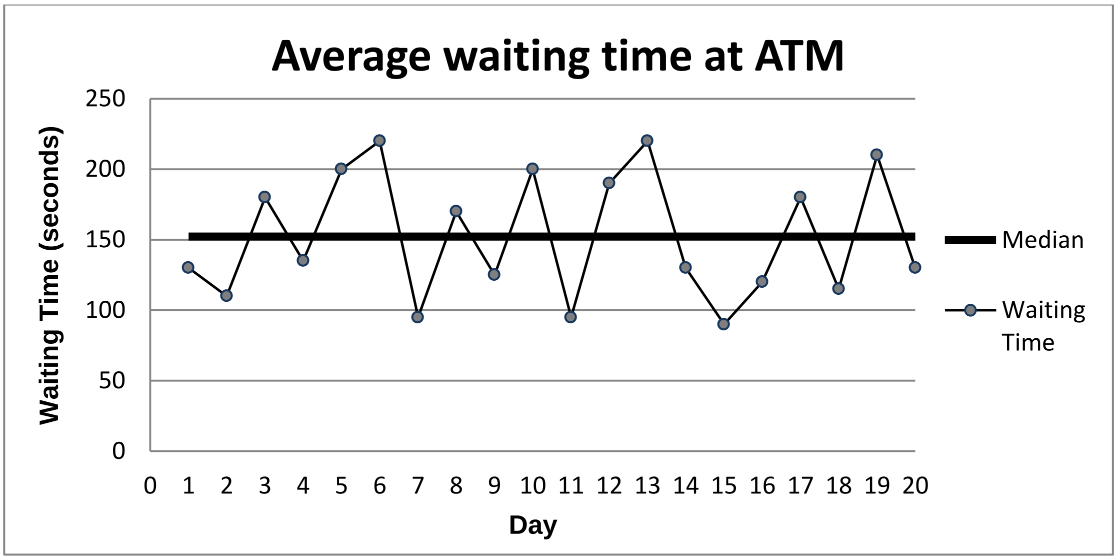


Figure 2.14: Run chart

A *cycle* is a wave of periodic low and high points that tends to appear and disappear with some degree of consistency. Cycles can therefore provide somewhat accurate performance predictions when identified and understood. Several factors can cause cycles: these include morning start-ups, periodic shift of workers, and operator fatigue.

Dr. Walter Shewart suggested that a minimum of 100 data points without special cause of variation is needed before one can assume that a process is in statistical control. However, the absence of process patterns does not necessarily mean that a process is stable. On the other hand, the presence of some process patterns can be the result of improvement activities, which are expected to produce positive results.

2.9 Review improvement

There will always be obstacles with the implementation of new ideas, strategies and tactics within an organisation. Results of pilot improvement might even turn out to be opposite of what was predicted. Unfortunately, many see people these results and obstacles as failures. However, the success of improvement relies on the experience and knowledge gathered thought the review and reflection of these so called failures.

Pilot improvement should be reviewed to identify and learn from obstacles such as rigid policies, inherent behaviours, and absence of resources. When obstacles are thoroughly understood it will be easier to develop effective and sustainable solutions.

Review should not only address obstacles and failures, it should also focus on the success factors. Typical factors include a well-defined project plan, clear vision and objectives, top management support, employee involvement, training and education, and effective communication. This is important because managers often neglect to identify the success factors that will lead to successful and sustainable improvement.

2.10 Adopt or adapt

The final step of the basic improvement cycle is to decide how to continue with future improvement efforts. This decision is based on the information generated through data analysis and improvement reviews. The three options are to abandon, adapt, or adopt ideas that were developed and implemented throughout the improvement cycle.

Abandon: This means that the basic process improvement cycle is restarted with a new focus area in mind. The result of this decision is a major loss of many resources that were included in the cycle up to now. One should therefore never decide on idea abandonment after one failed improvement attempt; rather consider adapting ideas.

Adapt: Many situations only require that ideas are somewhat adjusted to deal with policies, behaviours, and physical limitations. The magnitude of the needed adjustment depends on the success of pilot improvement. In serious cases it may be necessary for the team to repeat some steps of the improvement cycle or even the entire cycle.

Adopt: The team may decide to adopt some or all of the improvement ideas after the successful completion of pilot improvement. This decision must be supported with an appropriate infrastructure to move towards organisational wide implementation. This includes investment in training, education and the relevant resources to increase the chance of successful and sustainable application. The people that were responsible for the pilot improvement should also mentor and support the rest of the organisation.

The nature of continuous improvement means that the successful completion of one improvement activity should lead to the start of another; in other words, successful exploitation of ideas leads to new opportunities to be identified. However, the team should first celebrate the successful completion of the basic process improvement cycle and each participant is to be congratulated on their contribution to success. [15]

3. Lean Thinking

Lean thinking is a common continuous improvement methodology that focuses on the identification of value added operations and elimination of waste. The goal of this focus is to improve process efficiency, quality and responsiveness. This is achieved with the creation of flow, in reaction to customer pull, and in pursuit of perfection. [35]

Lean thinking can be applied to resolve various organisational issues such as high inventories, long internal lead times, high defect rates, low customer satisfaction, high process costs, and frequent bottlenecks. This requires a cooperative culture that strives to learn and solve problems for the successful generation and implementation of solutions through a wide range of tools and techniques. However, the methodology lacks the statistical tools often required to achieve true lean process capabilities. [36]

History of lean thinking

The origin of lean thinking can be traced back to 1913 when Henry Ford started the flow production line for the Ford Model T. Ford implemented several of the principles of Frederic W. Taylor, which focused on extensive time studies and projects to create standard work in order to increase process efficiency and throughput. This approach was the first case of real process integration, which introduced the idea of flow. [37]

The problem with Ford's method was its lack of flexible. It relied on a push system, where Ford set the level of production for a specific product, and the process didn't allow for any modifications or changes to the final product. This mass production approach led to large inventories of unsold automobiles, and therefore huge amounts of wasted money. So even though this process was efficient, it was not effective. [9]

The major change came in the 1950s when Toyota adopted and improved the Ford production system under the guidance of Taiichi Ohno and Shigeo Shingo. They recognised the limitations of Ford's system and customised the production process to suit the needs of the Japanese market, which called for lower volumes and larger variety of cars. Ohno then developed the renowned Toyota Production System (TPS) to maintain continuous flow and create flexible processes that can manage changes in demand; the goal of the TPS is highest quality at lowest cost and shortest lead time.

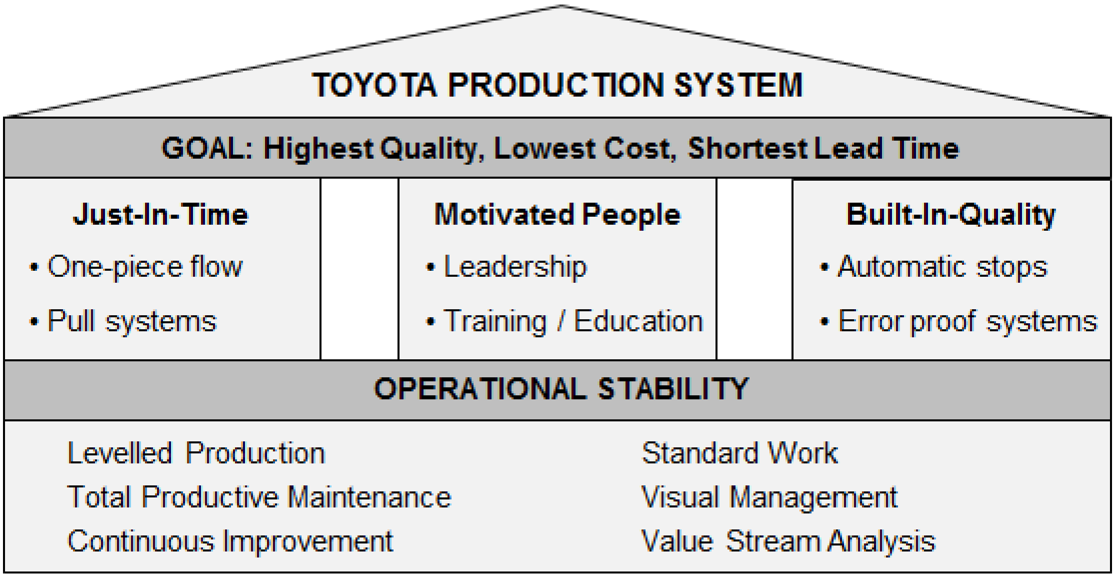


Figure 3.1: Toyota Production System framework

Toyota recognised the potential of process workers to solve problems and improve processes, which culminated into a culture that always strives to solve problems and learn from experiences. This recognition of workers was opposite to the harsh attitude at Ford and its undignified job structure. For that reason, when other manufacturers became aware of Toyota's success, the common agreement was that TPS would not work outside Japan because of the different mindset of the Japanese employers. [37]

In 1982 Toyota started a joint venture plant called New United Motor Manufacturing Inc. (NMMI), which was their first plant in the United States, together with General Motors Company (GM). They joined forces with GM to benefit from their established supplier network, but the plant itself was run solely by Toyota with their TPS. The success of the plant made it clear that the TPS did work in the United States as well, because a plant that had been run by GM since 1962 started to win multiple awards and ranked among one of the most productive manufacturers in North America. [37]

Jim Womack, Daniel Jones, Daniel Roos and their research team coined the term *lean manufacturing* in 1990 when they wrote the book entitled "The Machine That Changed the World", which they based on their study of the TPS. They also made the argument that lean ideas can be applied in any organisational sector or business environment, which even made it relevant to companies in the service industry. [36]

Table 3.1: Summary of the 14 lean principles

Categories	Principles
Philosophy	1. Base management decisions on a long-term strategy
Process	2. Create continuous process flow 3. Use pull systems to avoid overproduction 4. Level out the workload 5. Build a culture that stops to fix problems 6. Standardise tasks and processes 7. Use visual control so no problems are hidden 8. Use only reliable, tested technology that serves your people
People and Partners	9. Grow leaders who live the lean philosophy and teach it to other 10. Develop exceptional people and teams 11. Respect your network of partners and suppliers
Problem Solving	12. Go and see for yourself to thoroughly understand the situation 13. Make decisions slowly by consensus and consider all options 14. Learn through relentless reflection and continuous improvement

Dr. Jeffrey Liker, an industrial engineering professor at the University of Michigan, published "The Toyota Way" in 2004. In his book he shared years of research and experience with the TPS. He summarised the strategic and technical aspects of this system in 14 principles, grouped into four categories, as shown in Table 3.1. The book also recognised that lean is not just a set of tools, but rather a way of thinking. [38]

Focus of this chapter

The principles identified by Dr. Liker provide a clear representation of the aspect that drives lean to be a successful improvement methodology. This report discusses the four main categories separately to distinguish between these otherwise integrated principles for easier interpretation. However, the process principles are not discussed in sequence, because it is discussed in terms of the five step lean improvement cycle that was developed by Womack and Jones to provide a practical lean approach. [38]

3.1 Principles

Dr. Liker determined that a central part of lean is the management of a cooperative culture that strives to solve problems and learn through reflection and continuous improvement. He then identified 14 strategic and technical principles that drive this lean approach and organised them into four improvement categories, as follows: (1) philosophy, (2) people and partners, (3) problems solving, and (4) process focus.

3.1.1 Philosophy

At the most fundamental level, top management must drive the long-term strategy that strives to add value to customers, society, the community, and its associates through an organisation that can adapt to changes in the environment. This principle provides the foundation to rationalise investment in organisational improvement. [39]

Principle 1: *Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals*

Decisions made by top management must provide the opportunity to grow and align the organisation towards a common vision and mission that is more important than short-term financial goals. The basis for management focus must therefore be on the evaluation of business functions to ensure that they generate value for the customer.

The absence of top management support is one of the main reasons that lean efforts end in failure. This is because top management is responsible to set an example and demonstrate lean ideas in order to create a culture of change. Toyota showed how success can be encouraged when people are aligned towards a common purpose that supersedes any short-term strategy. Managers should therefore be educated in lean principles to promote the philosophy and implement the long-term strategy. [37]

3.1.2 People and partners

Toyota states that they don't just build cars, they build people. This is based on their belief that people are the greatest asset of the organisation, and if you make little investment in this resource, it will prove little return. Any organisation can use lean tools and techniques but that does not make them successful. It is the people that apply these tools and techniques that are most crucial to ensure future success. [40]

Several of the lean thinking tools and techniques make problems more transparent to create an environment that challenges people and forces them to think. This may not always be enjoyable but it helps to develop better and more confident workers. The two critical factors to succeed in this environment are respect for each other to build mutual trust, and teamwork to stimulate individual growth and share knowledge. [38]

Dr. Liker identified three principles that refer to people and partners: (1) grow leaders who fully understand the work, live the philosophy, and teach it to others, (2) develop exceptional people, and (3) respect your extended network of partners and suppliers.

Principle 9: *Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others*

Effective leadership is important to successful improvement efforts. Leaders serve as exemplars of the organisational philosophy and best practices. They also promote the lean thinking culture by showing their daily commitment to lean operations. This approach is the basis for leaders to lead people forward towards the ideal state, while a management approach would only focus on the functions of the current state. [41]

Lean practitioners pride themselves in the development of leaders from within the organisation. This ensures the people in leadership positions thoroughly understand the principles of the organisation and the actual situation at operational level. It also increases employee loyalty and give them the opportunity to grow and develop skills.

Although leadership is a crucial success factor, it is not necessary to have a large leadership hierarchy because leaders develop and mentor others to do many of the tasks often done by leaders within other companies. This is due to both a top down and bottom up management approach, which means that even though management initiate and drives the lean philosophy, employees are still responsible to use their own judgment and make decision within the context of best practice methods. [40]

Principle 10: *Develop exceptional people and teams who follow your company's philosophy*

The development of exceptional individuals to achieve excellent results within the organisational strategy is important for the integration of social systems together with technical systems. Continuous efforts are therefore made to teach individuals how to work together as teams within a strong, stable culture that shares the same values and beliefs. This is both an enabler and result of successful improvement efforts. [42]

A study done by IBM in 2012 shows CEOs consider collaboration as the number-one trait in employees, with 75% of CEOs that call it critical. Collaboration in the form of cross-functional teams is used to coordinate work, share knowledge, and motivate people, while individuals do the value added work. It is therefore crucial to cross-train people with job rotation to create flexible teams. People must also be cross-trained to increase their knowledge and make them feel focused, involved and motivated. [40]

The IBM study also shows more organisations encourage openness because CEOs believe their organisations will be impacted more by the pressure to be open than the need to control their employees. Open organisations empower employees to act on their own ideas and use organisational resources. They also encourage the free flow of ideas, creativeness and innovation to create responsible and loyal employees. [43]

Principle 11: *Respect your extended network of partners and suppliers by challenging them and helping them improve*

Lean thinking stretches further than internal development. Business partners should be respected and treated as an extension of the organisation. It is also important to value their contribution and assist them to reach goals that challenge them to grow and develop. Therefore, current suppliers with good reputation have job security, even when cheaper alternatives become available; on the other hand, new suppliers must first pass rigorous tests to earn their place as part of the business network. [44]

Toyota developed a supplier partnering hierarchy to describe the needs of suppliers in order to make them good partners. This consists of seven levels that build on each other to promote a long-term relationship. The main success factors are trust, care, and mutual welfare. Furthermore, discipline and joint improvements are also crucial, and organisation can challenge each other as motivation to improve even more. [16]

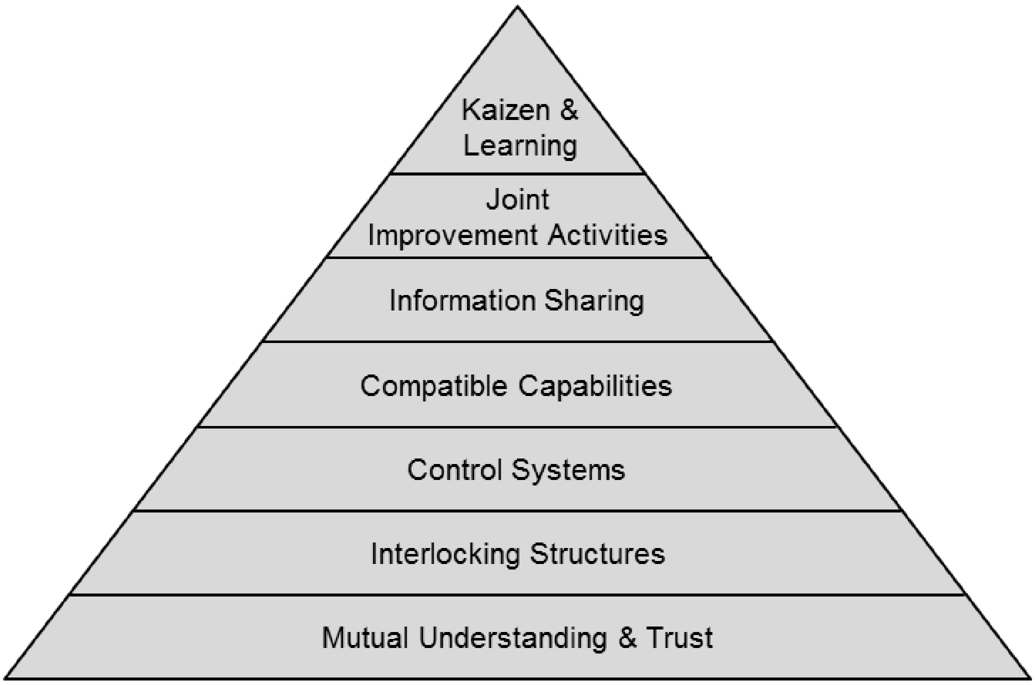


Figure 3.2: Supplier partnering hierarchy

3.1.3 Problem solving

Continuous problem solving forms part of a lean culture and it is both a result and enabler of sustainable and successful lean operations. The aim of the culture is to guide employees through change processes towards lean values and best practices that provide the organisation with a competitive advantage. This leads to high quality, low cost, short lead time, high employee morale, and a safe work environment. [36]

Dr. Liker identified three principles that refer to repeated problem solving: (1) go and see for yourself to thoroughly understand the situation, (2) make decisions slowly by consensus and consider all options; implement decisions rapidly, and (3) become a learning organisation through relentless reflection and continuous improvement. [16]

Principle 12: ***Go and see for yourself to thoroughly understand the situation***

Lean emphasises direct observation of the actual process to understand the actual situation. Even top management should apply direct observation as much as possible because lean does not tolerate remote data analysis on the basis of reported data or theoretical process standards. Therefore, people that are responsible to analyse data and make decisions must spend time at process level to understand the process. [38]

This principle is supported by the “standing in the circle” technique that was used by Taiichi Ohno to train new employees. It requires the employee to stand and observe an operation carefully for 8 hours or more, to identify conditions within the operation that cause waste. After the first few minutes to an hour, the mind has observed the larger issues and might conclude that everything has been seen, but it may take four to eight hours to transcend to a higher level of awareness. Once this is mastered, a shorter observation will provide a detailed comprehension of a studied operation. [45]

Principle 13: ***Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly***

A lack of employee involvement is one of the main reasons for lean implementation failures. The problem is that ideas are not communicated throughout the organisation because management often solves problems and forces ideas onto workers without their input in the development and selection of these ideas. However, lean believes the development and selection of ideas are just as important as the quality of ideas.

Complete comprehension of the studied process is crucial to make decisions through consensus. The affected people must then reach agreement on the appropriate idea for implementation through problem identification and idea generation. Although this consumes some time, it broadens the solution base and gives participants ownership of the idea. The selected idea should then be implemented as fast as possible. [46]

Principle 14: *Become a learning organisation through relentless reflection and continuous improvement*

The act of reflection is an attitude and philosophy, and also the basis of continuous improvement. Lean considers it a sign of strength when individuals can acknowledge their mistakes and act on them. People should therefore always learn from mistakes to identify the cause of the problem and then develop effective countermeasures. [47]

Continuous improvement is an important driver that encourages people to learn from stable processes. This requires organisational wide reflection after each milestone so that people can gather knowledge from experience instead of blaming each other for mistakes. The gathered knowledge can be protected by a stable base of personnel and an active knowledge distribution structure. This means the organisation should have the capacity to build on past experience and execute incremental improvements to move towards a culture that continues to learn and develop through reflection. [38]

3.1.4 Process focus

Lean thinking organisations have a process orientated management view that relies on knowledge of operational interdependencies to align customer requirements with process specifications. A process view focuses on what needs to be done and how to do it within organisational values and beliefs. This view also breaks down barriers to encourage communication between functional units, create flexible processes, and enable cross-functional analysis to determine organisational wide performance. [48]

The process view is opposite to the functional orientated management view that aims to optimise functions or operations in isolation. A functional view relies on a formal hierarchical structure that can result in the optimisation of individual functions and this may harm the system as a whole. On the other hand, people are allowed to specialise in their field of expertise and a smaller number of specialists are required because functions are centralised. The different views are represented in Figure 3.3.

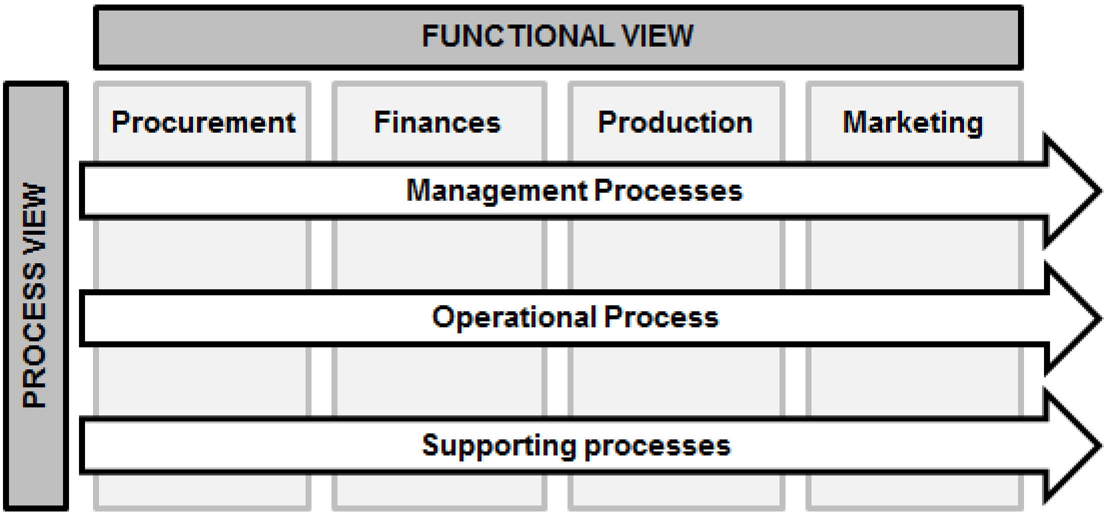


Figure 3.3: Difference between process view and functional view

The process view is supported by means of a process-based layout, which is also referred to as a cellular layout. This is an ideal situation where workstations and equipment are arranged in a sequence that supports continuous process flow with minimal transport, delay, and inventory. Employees must therefore be trained across operations so that they can easily shift between different workstations. This is a key enabler for faster throughput, as well as the reduction of resource requirements. [35]

Process focus implementation is expanded into five detailed process improvement steps, specified by Womack and Jones. These steps, together with the relevant tools, are accepted with key importance to successful lean execution. However, they serve only as guideposts, because the current situation of every organisation is unique. [36]

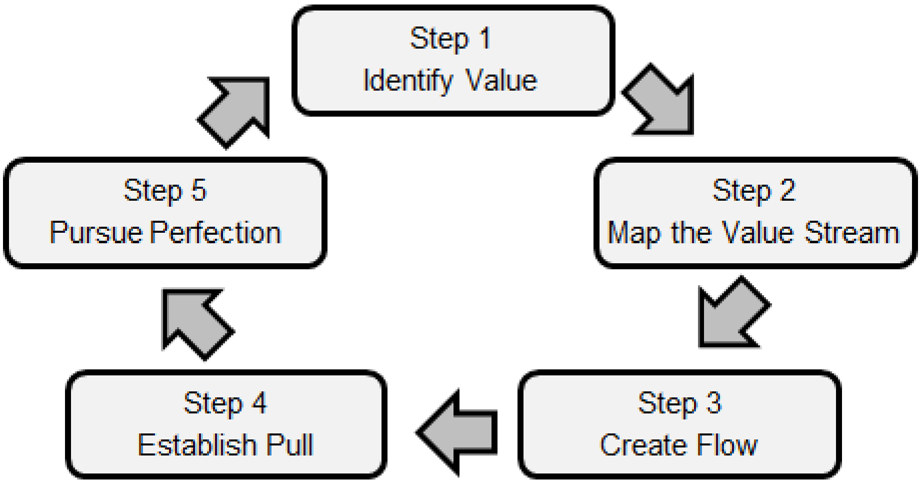


Figure 3.4: The five lean improvement steps

This report discusses the five lean improvement steps in detail to act as a process focused improvement roadmap. Several lean tools and techniques are discussed within these steps where appropriate. This is important to support the roadmap, but it is more important to understand how these tools and techniques should be applied.

Principle 8: *Use only reliable, thoroughly tested technology that serves your* people and processes

The foundation for improvement is stable, reliable, and predictable processes. It is therefore crucial to be cautious about implementation of new or untested technology in the system. Processes should first be improved with available techniques, tools, and people, before current technology can be considered for implementation. Only after this can the improvement team determine if additional improvements can be made by the acquisition of new technology that fit in with organisational policies. [49]

Note that lean is not against the use of technology, it just perceives technology in a different manner, one driven by a practical purpose. Technology must be used to support value-added processes and not to replace people, while it functions within the boundaries of organisational values and beliefs. In other words, technology must be used to support process thinking, and not be used as a substitute for thinking. [16]

Organisations should be interested in technology and encourage workers to consider new, creative approaches to work, which can include technology. Once the manual process is stabilised it can be automated on condition that it does not distract people from the value added work. Technology is best used by process workers, right where the work is performed, so that additional people are not required for data entry. [38]

3.2 Identify value

The challenge in lean organisations is to add value faster than costs and still deliver competitive products and services. Many of these costs are hidden in processes that are inefficient, produce too much or not enough products, produce defects, produce the wrong product or the right product at the wrong time, and rely on inspection. The source of these unnecessary costs can be traced back to non-value added activities.

Value, and therefore non-value, is defined by either internal or external customers in terms of product or service requirements. Furthermore, value is only significant when it satisfies customer needs at the right time, at the right price, and in the right amount.

Table 3.2: Difference between value added and non-value added activities

Process Activities	
Value Added	**Non-Value Added**
• Necessary to meet customer requirements • Assist in the production of the product or service • Represent an output that the customer will pay for • Crucial to ensure that the process functions in the right manner • Improve quality or resolves problems that affect satisfaction	• Do not impact customer requirements • Add redundant steps that create waste or rework • Represent an output that the customer does not care about • Performed because of inefficiencies in the process • Done because the original output failed to meet requirements

Lean focuses on the optimisation of value added activities and also the reduction or elimination of non-value added activities. This requires that people understand the definition of value, otherwise a lot of non-value added activities could be performed that result in waste; continuous waste elimination is therefore a main lean principles that organisations implement to reduce non-value added activities. However, some activities are non-value added but required, such as administration and maintenance.

3.3 Map the value stream

Womack and Jones define the value stream as "the set of all the specific actions required to bring a specific product through the three critical management tasks of a business: problem solving, information management, physical transformation". [36]

Once a theoretical distinction between value and waste has been made from the view of the customer, the process can be analysed with a value stream map. This map is used to document and analyse the flow of material and information to find non-value added activities. Mike Rother and John Shook adapted this lean approach from the successful material and information flow diagrams created by Toyota. [50]

Value stream maps were first introduced to document tangible processes. Womack and Jones then expanded this concept to the entire business environment. This is because they realised that intangible flow can also be documented with a strong timeline focus. The map also shows the interdependencies between functional areas.

The most important part of a value stream map is to document and understand how the actual process is performed. Therefore, start with a simple flowchart to create a basis. Then use the steps below to transform the flowchart into a value stream map.

Step 1: Calculate takt time. Takt is a German word for metronome. This is the rate at which a process should run to meet customer demand, expressed in maximum time allowed per unit of output. It is used to balance capacity with customer demand. [38]

Function	Description	Calculation
"#"	Number of shifts per day	1
"x"	Number of hours per shift	8
"x"	60 minutes per hour	60
"="	Number of minutes per day	480
"-"	Less: Break (minutes)	60
"-"	Less: Setup Time (minutes)	45
"="	Total minutes available per day	375
"/"	Average demand per day (units)	750
"="	Takt time (minutes per unit)	0.5
"x"	60 seconds per minute	60
"="	**Takt time (seconds per unit)**	**30**

Figure 3.5: Takt time calculation

Display this information in the top right hand corner of the paper that the map will be created on. Also draw in a saw top box that represents the customer. Note that it is better to draw a rough paper draft before a detailed map is shared with management.

Step 2: Construct the material flow in the bottom centre of the page. This includes the operations boxes and data boxes. The operations boxes represent single operations in the process. The data boxes provide information about the cycle time and number of operators. Additional information can include changeover time, defect rate, uptime, and capacity. This data should be validated before further analysis is performed.

Step 3: Add the inventory. Count the number of pieces between two operations to determine the inventory, or work-in-process (WIP). This is represented with triangles between the two relevant operations. Then divide the number of pieces by the daily demand, which was used to calculate takt time, to convert inventory into supply days.

Step 4: Construct the information flow. Start with the communication channels from production control, such as MRP, to each operation. Use straight arrowed lines for manual handover of information, otherwise use lightning bolt arrowed lines. Also construct information flow from customers and flow to suppliers. Furthermore, specify the frequency of these information handovers; such as daily, weekly, or monthly.

Step 5: Add in the timeline. Draw a saw tooth line on the bottom of the material flow to separate the value added time (bottom of line) taken from the data boxes, from the non-value added time (top of the line) taken from the supply days info. Sum the value added cycle times and the non-value added supply days. Then multiply the supply days with the total available minutes per day to determine lead time minutes. Lastly, divide the cycle time by lead time minutes to determine process cycle efficiency. [50]

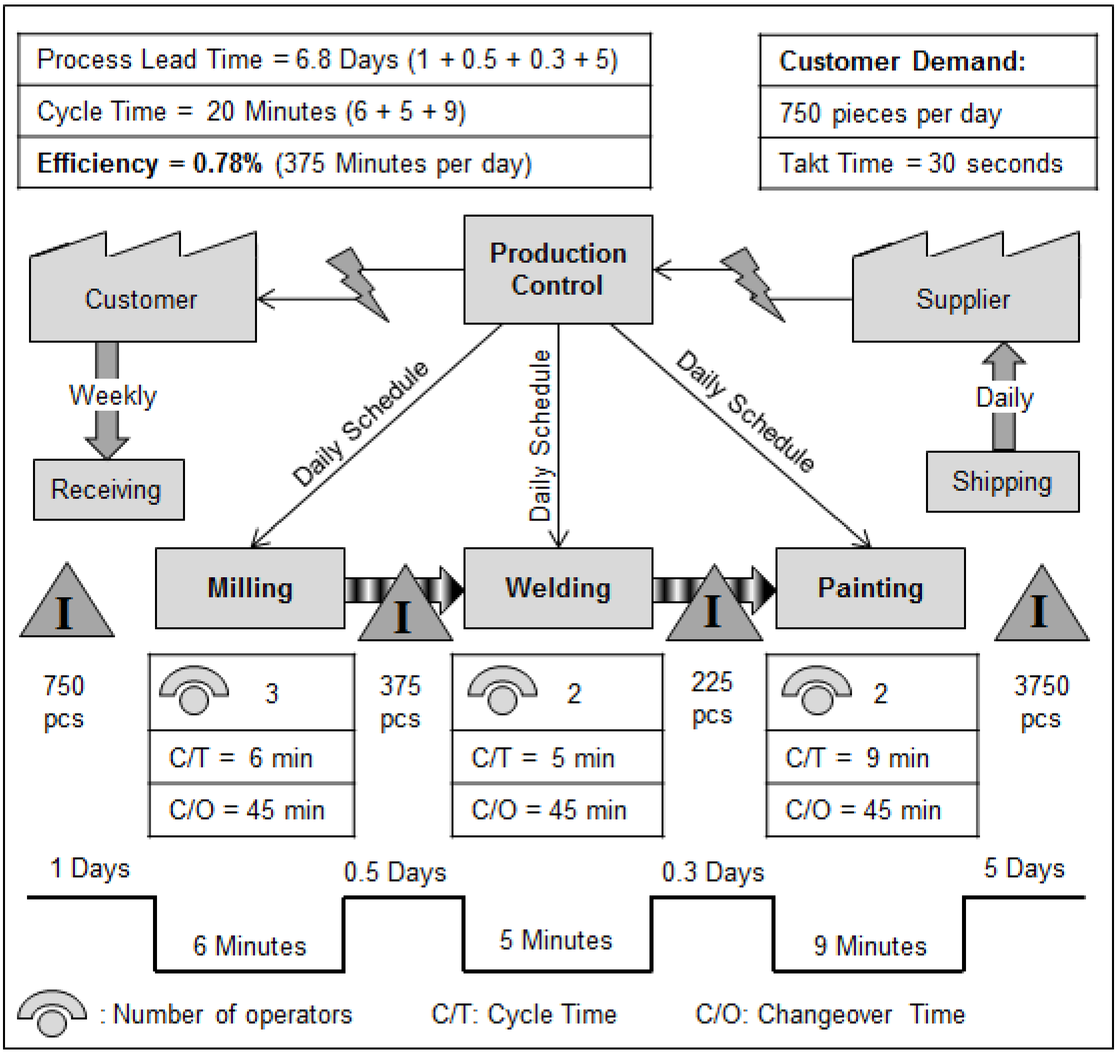


Figure 3.6: Value stream map

3.4 Create flow

Continuous process flow, also called one-piece flow, is the rapid, uninterrupted, step by step movement of material or information through a system. Improvement efforts are directed towards flow once value added and non-value added activities have been identified. The importance of flow is to ensure stable operations, which is the foundation for the TPS. Flow is therefore recognised as a crucial lean principle. [38]

Principle 2: *Create continuous process flow to bring problems to the surface*

Continuous flow means that material and information moves through efficient process steps with minimal delays and the shortest travel distance. Even though flow focuses on value added activities to increase value and reduces throughput time, it is a fragile approach that forces problems to the surface. However, this is a positive and desired effect that is crucial to continuous improvement and the development of people. [17]

The opposite of continuous process flow is batch production. Various lean tools and techniques are available to move away from this traditional method that pushes large quantities of material and information through the system at the same time. Most of these tools focus on the establishment of stable operations that produce one unit at a time. Although flow is not always practical, it provides many opportunities to improve.

There are several advantages to continuous flow. First, workers can detect and fix defects easier in smaller batches. Second, processes are more flexible because of short lead times and quick changeovers that accommodate changes in customer demand. Third, value added work is easier to identify because operations are more transparent. Fourth, operations are pushed together to better utilise floor space and eliminate excess inventory. Fifth, employee morale increases because of transparent processes and visible improvement. Sixth, standard procedures and an organised environment can reduce the likelihood and severity of hazardous occurrences. [38]

3.4.1 Waste elimination

The identification and elimination of waste is a primary lean principle. Taiichi Ohno once said: “All we are doing is looking at the time line from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line removing the non-value added wastes.” Waste elimination is therefore the first step towards the creation of process flow, once the value stream is mapped. [51]

Waste elimination is also important to demonstrate the essential strategy of process flow. Many people implement continuous flow only as the step by step movement of material or information through a system, but the main purpose of flow is to create a connected value stream in which process workers are being forced to think and solve problems. It is therefore important to understand that waste elimination supports the philosophy behind process flow, and not only the physical interpretation of flow. [38]

The key to waste elimination lies in this paradox: In order to improve, the condition must be made worse. This is because operations become more dependent as they are linked together to create waste free work cells; so when one operation shuts down, the next also shuts down. Therefore, waste elimination often sounds easy, but it cannot be implemented to create flow without a certain amount of discomfort. [16]

Taiichi Ohno identified seven types of waste that should be eliminated to achieve a waste free manufacturing process. However, these have since been adapted to be relevant to any business environment. This section focuses on the definition of these wastes, as well as an additional eight waste. Although many of these wastes can be eliminated straightaway, the tools and techniques that are discussed throughout this chapter can be applied to deal with more complex waste in a systematic manner. [52]

1. Overproduction

Overproduction is the production of outcomes when they are not needed, at a faster rate than is required, and in greater quantities than desired by the customer. Ohno considered this to be the fundamental waste, because it enables most of the other wastes. This can also lead to an increase in process cost and resources requirements.

The cause of overproduction can be traced back to ineffective communication, a poor production schedule, inaccurate forecasts, inadequate production management, and excess production to make provision for demand variation. Batch flow, which pushes extra material and information into the system, can also lead to overproduction. [53]

Overproduction can be countered by a schedule that enforces production at the rate of customer demand. People that are kept busy with pointless work just to increase workforce utilisation are also a form of overproduction, which can lead to extra labour requirements. It is therefore critical to pace the production rate to match demand. [37]

2. Inventory

Inventory waste can be physical or a queue of information. This includes excess raw material, WIP, safety stock, and products that are not needed at the moment. These are considered to have a significant impact on process performance because it hides potential problems such as longer lead times, obsolescence, damage goods, delays, equipment downtime, late deliveries, uneven production, and long setup times. [16]

High inventory is often the result of overproduction. Therefore, overproduction should be addressed together with high inventory to determine if there exists any correlation between them. These wastes provide the initial focus to execute waste reduction and elimination activities because both of them can aggravate other types of wastes. [38]

Although considered a waste, the careful use of inventory may be advantageous until processes are stable. Inventory is therefore frequently used to provide a safety buffer against variation and compensate for a lack of flexible processes. This is considered a weakness and should serve as a constant reminder of the need to strengthen the process. The ideal process should have no inventory, but this is not always practical because of variation, and some processes also need some inventory to function. [53]

3. Transportation

Transportation waste is the pointless movement of inventory within the process, even when it is only a short distance. This includes product deterioration and damage from extended transport times, in which no value is created for the customer. Additional, indirect waste includes excessive moving equipment and several storage areas. [54]

Poor transportation practices can be caused by high levels of inventory and changes of priorities. Ineffective communication can also lead to work that is transported to the wrong person or department. Furthermore, a functional organisation perspective can increase transportation waste as work needs to travel between specialised functions.

4. Waiting

Waiting waste is defined as the time machines, work pieces, or people are idle and no value is added to the product or service. This includes employees that monitor automated machines and employees that stand around while they wait for supplies, tools, information, the next process step, capacity constraints, machine maintenance, and required resources. Another problem is the lack of immediate work opportunities.

The reduction of waiting time is crucial to create continuous process flow. Production must therefore be planned around the operation with the least amount of capacity so that idle time for downstream operations is minimised. Furthermore, implement total productive maintenance so that equipment and machine downtime is also minimised.

5. Defects

A defect is a nonconformance on one of many possible quality characteristics of an output that causes customer dissatisfaction. This includes defective work that must be corrected, reworked, inspected, or scrapped. These actions result in duplication of effort and are a significant waste of resources such as time, labour and material. [54]

Defects and defective outcomes can be the result of various quality issues such as unreliable processes, equipment issues, poor maintenance, lack of process control, and the absence of standard work. Also, poor communication may lead to incorrect information, inconsistent information, and insufficient information or instructions. [53]

Defects can be avoided or reduced with the presence of standard work procedures that provides instructions for consistent work performance. Also, processes can be designed to decrease the likelihood of defect occurrence and also for the proactive detection of abnormalities so that issues can be corrected as soon as possible. [38].

6. Over processing

Over processing is the execution of work activities that are not required to complete a process. A rule of thumb is to determine if the work will be visible to the customer in terms of value added to a product, service, or information. Furthermore, it is also a waste when a higher quality outcome is produced than is required by the customer.

Over processing is often one of the more difficult wastes to detect and eliminate, but it can be prevented by continuous comparison of customer requirements and process specifications to identify improvement opportunities. Process workers should also be on the lookout for opportunities to improve their usual standard work procedures. [53]

7. Motion

Motion waste is any pointless movement that requires a person to bend, reach, look for equipment, or walk when they perform a process and it does not add value for the customer. In other words, it is any form of motion that does not add value to the work.

Motion waste can be caused by poor workplace design and inefficient arrangement of resources. This include the time spent to learn how to function effectively in an inefficient environment and the time wasted when people search for tools, material and information that are not available where they are required. Other causes include the use of wrong or inefficient tools, which may lead to health and safety issues. [53]

It can be difficult to detect subtle movements, but there are many proactive tools and techniques that can be used to avoid unnecessary motion. The first step is to enforce standard methods for efficient work procedures with minimum movement. Then the workplace should be cleaned and organised to sustain a practical layout for tools and equipment so that they are always available when and where they are required. [38]

8. Talents

Talent waste, the additional “eighth” waste, is the underutilisation of employee skill and intellect. This waste includes people that do work without the required expertise and knowledge, and a lack of education opportunities. Employees that have partial responsibilities in terms of the process that affect them are also considered a waste.

The cause of talent waste can be traced back to a poor organisational culture, low to no investment in training and education, and poor employment practices. Employee skill and intellect that are ignored can also lead to wasted improvement opportunities.

Talent waste can be avoided when employees are empowered to make decisions with their own judgment, within the context of best practice methods. Encourage employees to utilise their talents and be innovative. Furthermore, implement job rotation to increase their area of expertise and their appreciation of the process. [40]

3.4.2 Standardised work

There can be no improvement without standardisation, because operations would most likely be performed in different ways by different people. This would lead to variation and unpredictable outcomes, which restricts process flow. Standardised work is therefore one of the first lean principles that should be implemented as a baseline for improvement activities. Also, when work is performed in a structured manner, successful implementation of lean improvement activities is more likely. [37]

Principle 6: *Standardised tasks and processes are the foundation for continuous improvement and employee empowerment*

Standardised work enforces stable, repeatable procedures in operations to maintain constant, predictable process output. This is based on the definition, clarification, and utilisation of methods that will ensure best possible results. However, it is a proactive approach that is used to identify problems and establish effective solutions. This is driven by people, not done to people, to ensure continuous improvement efforts. [16]

People closest to the work should be exploited to contribute towards standardization because of their direct experience and knowledge of the process; management must encourage employees to share their knowledge and experience. Standardisation is then used to capture this knowledge and improve the process, while people continue to learn and develop. However, best practice methods must guide this procedure to ensure that organisational values and beliefs are respected by every participant. [55]

Standardised work should not be confused with work standards. The latter evokes images of a rigid procedure where people use stopwatches to squeeze out every second of productivity; employees are also monitored and trained to ensure that they follow a specified, predefined method to perform work. This creates a bureaucracy where human will and creativity are wiped out and people become automatons. [35]

Standardised work is used to establish the appropriate method to perform work. The SDSA cycle is then used to evaluate this method; people must continue to analyse and improve standardised work through the development of better work methods. [15]

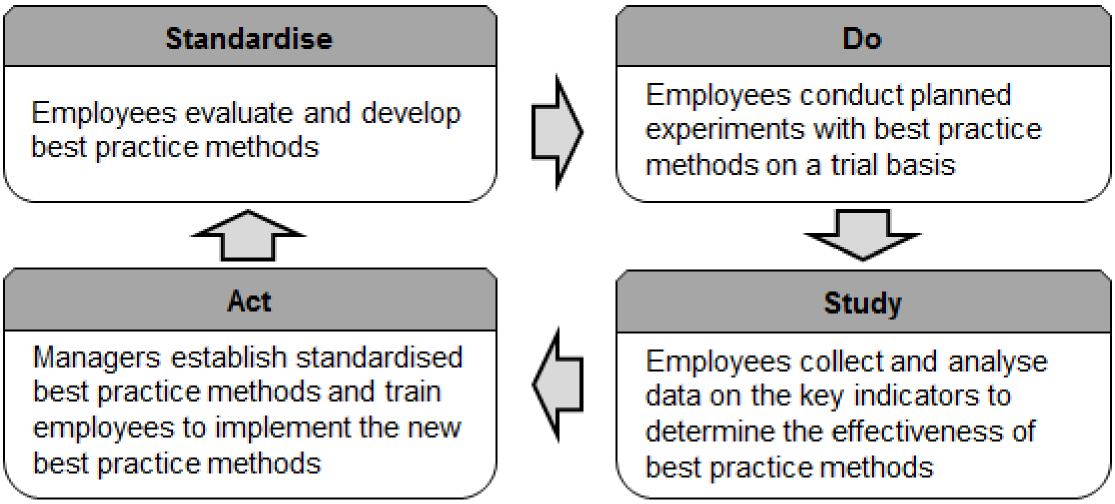


Figure 3.7: SDSA standardisation cycle

3.4.3 5-S movement

A clean and organised work environment is considered vital to support standardised work and should therefore be applied throughout the organisation. However, it is also the lean aspect that is most often demeaned because it is so simple. Nevertheless, the Japanese realised its importance and developed a basic technique that is used to promote good housekeeping actions. This technique is called the 5-S movement. [56]

The 5-S movement is a simple, yet powerful, technique that drives organisation wide improvement efforts because it is practical and low cost. The purpose is to create a cleaner and better organised environment to improve safety and performance. This technique rarely uncovers major opportunities to save resources, but its benefits are realised over time as it is used by more people. Employees should therefore be given ownership of their respective work areas to participate in this improvement approach.

The name "5-S" is derived from five Japanese words that begin with the letter S: *seiri*, *seiton*, *seiso*, *seiketsu*, and *shitsuke*. The English translations that match these are: sort, set in order, shine, standardise, and sustain. These are used to create a clean and organised workplace that encourages waste elimination and standardisation. [15]

Sort: Clear out every item that are broken, not usable, rarely used, or insufficient for a specific operation to only have what is needed, when it is needed. However, even the required items must be kept to an absolute minimum. Always continue to mark rarely used items, or items not used within a month, with red tags. These items should be reviewed and approved by the supervisor and then be placed in a marked storage area.

Set in order: Organise and arrange items so that minimal effort is required between activities. Label items and create adequate storage areas so that items are easy to identify and available for immediate usage. Daily items can be stored on a labelled shadow board, weekly items in labelled drawers, monthly items in cabinets labelled with pictures and text. Other strategies include painted floors, outlined work areas, and modular shelves. Visual control techniques should be used to support this step.

Shine: Maintain a clean work area. This makes problems more transparent and acts as a form of visual inspection that enables immediate problem solving. It also helps to keep items clean and in workable order, ready for immediate use. Shine should therefore be performed on a daily basis to promote a proactive maintenance system.

Standardise: Standardised methods and tools should be recognisable throughout the organisation to maintain and monitor the first three steps. This ensures uniform work methods throughout the organisation. Effective visual control can be implemented for easier identification of anomalies and variation. This includes clear work instructions, posters, scoreboards, charts, and the standard colouration of work areas and tools.

Sustain: Be disciplined and adhere to standardised work. This requires continuous evaluation of 5-S practices, and the cooperation of management and employees to make it happen. Management should audit 5-S regularly with standard checklist in the initial phase of implementation, but when 5-S is already a habit, teams can audit their own work areas in regular intervals while managers only do random inspections.

The 5-S movement should be integrated into more operations after successful initial implementation. This ensures continuous improvement and maintenance of the daily work environment. Use posters, pocket manuals, newsletters, performance reviews, and department tours to distribute and promote 5-S information until it becomes part of the organisational culture. Remember to use regular audits to stay disciplined and implement visual control to encourage 5-S practices throughout the organisation. [38]

3.4.4 Visual control

In modern organisations the ideal environment is paperless and important process information is online. However, people long for a visual environment with charts and graphs, where they can see at a glance whether their work is in a standard condition of deviation; even though robots do not care for visual control, people do, and the system should be designed to support people. Well-designed and well-placed charts can also be an obvious location for effective discussions within the affected area. [57]

Principle 9: ***Use visual control so no problems are hidden***

Visual control is used to affect behaviour and communicate information to a broad group of people at once, without text or other written instructions; it is the practical application of the proverb that states a picture is worth a thousand words. Visual control should therefore enable people to absorb information without distractions. [16]

The important aspects of visual control are location and information; Charts, graphs, and posters must provide relevant information where it is needed. These should then be maintained with updated information to act as focal point for performance reviews.

Table 3.3: Visual controls

Visual Controls		
Description	**Purpose**	**Application example**
Information Boards	Display information that convey strategic vision and mission statements	Boards and posters placed at strategic locations with the companies vision and mission
Production Boards	Display information about production requirements	Tables, boards, posters, production schedules, maintenance schedules, quality and quantity graphs
General Performance Boards	Provide a dashboard to display current status of specific characteristics	Customer satisfaction, days without accidents, revenue, turnover, profit
Location Markers	Indicates the location of parts, tools, and material	Tape on floor, numbered locations, colour coded areas, painted areas
Standardised Methods	Indicates appropriate best practice method to perform efficient work	Work sequence charts, flow diagrams, photographs and videos
Tags	Indicates abnormal or special conditions that requires attention	Red tags for excess or obsolete items, scrap and defective material, and broken items
Kanban	Controls production and movement of material	Cards, containers, bins, signal flags

There are four main opportunities to implement effective visual control. First, use the 5-S movement as a guide to initialise visual control. Second, use labels and signs for different parts, materials, and tools to improve visual identification. Third, define standardised work practices and look for ways to visualise communication of proper procedures. Fourth, implement visual control to provide performance feedback. [12]

3.4.5 Load levelling

The traditional batch oriented production system encourages management to collect orders for a whole week, run them through a MRP system and generate a production schedule for a week so that the number of changeovers is minimized and the amount of available production time is maximized. However, lean practitioners know that this approach also increases inventories, lead times, quality problems, and process cost.

The problem with this approach is that customers do not submit orders for specific batch sizes, even though batch production is the norm. This also creates issues with alignment of resources to keep up with demand fluctuation; changes in demand can either lead to capacity shortage or surplus. This causes unevenness and overburden.

Unevenness is any variation that leads to unbalanced situations. These situations mean that resources must be available for the highest level of production, even if average requirements are much lower. Even though it is common for demand to be uneven, the problem is often hidden with batch production. Demand must therefore be levelled for the successful implementation of flow. Other causes of unevenness include problems such as defects, equipment downtime, and lack of resources. [37]

Overburden is any activity that pushes personnel or equipment beyond natural limits and causes unreasonable stress or effort. This includes the use of a machine or tool to perform a function that it is not designed for, which can lead to breakdown and defects. Also, from a social perspective, it can be the exploitation of manpower and insufficient employee preparation that leads to safety, ethical and moral issues. [37]

The only way to create continuous flow is to have stable processes. This requires the elimination of unevenness and overburden, and it also ensures that the organisation is not forced into a reactive mode. Any attempt to standardise a chaotic process with high level of variability will lead to frustration, because it is not possible to standardise variation. The production schedule must therefore be levelled to deal with fluctuations.

Principle 4: *Level out the workload*

This principle is to level total demand over a period of time, rather than to produce output in relation to the actual fluctuation of customer demand. Initial attempts to level the workload may require customers to wait for a short period of time so that daily process volume and mix can be balanced. However, once production is almost levelled, the process will be flexible enough to respond to changes in demand. [58]

Most lean processes are often balanced to support a cycle time some percentage below takt time to compensate for variation, even though the ideal balanced process strive to have little or no waste. However, in the ideal process, any operation can become the constraint if there is fluctuation in performance or customer demand. [40]

Sometimes selective addition of inventory waste is recommended to avoid a system where any operation can become the constraint at any moment. Even though this is contrast to lean belief, levelled workloads require a combination of build-to-order and build-to-stock, based on predictions. Although it seems wasteful to keep some final good inventory, far more waste can be removed with a balanced process output. [16]

The build-to-stock approach is used for relatively high volume output that you know the customer will buy, and stock is continuously replenished through the application of a pull system. The built-to-order approach is used for less predictable customer demand. Then a third stream of safety stock provides excess inventory to maintain balanced process output when demand is low and high demand was expected, or to provide safety stock for unexpected high demand. These three approaches should be combined to provide sufficient information for a levelled production schedule. [38]

Original Operator Schedule		
Operation	**Operator**	**Time**
1	A	35
2	B	25
3	C	10
4	D	10
5	E	15
6	F	10
7	G	18
8	H	17
Total Time		**140**

Number of operators required

$$\frac{\text{Total Time}}{\text{Takt Time}} = \frac{140}{40} = 3.5$$

Operators required = 4

Operators currently used = 8

50% less labour requirement

Balanced Operator Schedule		
Operator	**Operations**	**Total Time**
A	1	35
B	2, 3	35
C	4, 5, 6	35
D	7, 8	35

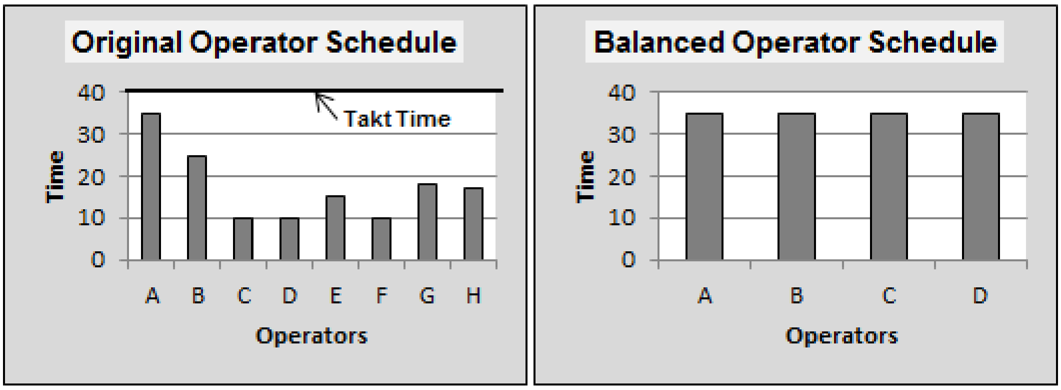


Figure 3.8: Load levelling (operator schedule)

Part		A	B	C	D	E	F
Six-Day Forecast		720	480	360	360	300	180
Part	Average Daily Demand	Balanced Production Schedule					
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
A	120	120	120	120	120	120	120
B	80	160	0	160	0	160	0
C	60	120	0	120	0	120	0
D	60	0	120	0	120	0	120
E	50	0	100	0	100	0	100
F	30	0	60	0	60	0	60
Total	**400**	**400**	**400**	**400**	**400**	**400**	**400**

Figure 3.9: Load levelling (production schedule)

The essence of load levelling is to create a schedule that deals with unevenness and overburden. This means the creation of a levelled production volume and mix to level out the demand on people, equipment, and suppliers. The key is to separate product groups and isolate variation to regulate a standardised, but flexible production schedule.

Instead of large production quantities of similar products in a day, break products into groups and often change between different product groups. The advantage of this method, in addition to lower inventories and rapid awareness of quality problems, is that as the demand for a specific product mix or volume changes it is easy to adjust production without a new schedule or the need to rush orders through the process.

Initial implementation of load levelling may require a considerable amount of similar products to be produced in a single run because of long changeover times. This is because load levelling is an incremental approach that always aims to refine the production schedule to produce different product groups in more frequent intervals and smaller batch sizes. This approach is a direct application of the ideal one-piece flow concept that lean strives towards. The next step is therefore the identification of opportunities to reduce changeover time to support frequent product group changes.

3.4.6 Single minute exchange of die

Single minute exchange of die (SMED) is a technique used for rapid changeovers that allow smaller batches to be processed, while flow is increased and production is still economical. The phrase “single minute” should not be taken literally, but rather seen as a goal to reach setups that can be completed in fewer than 10 minutes. [59]

SMED actions are required to accommodate an increased demand for larger product selections, reduced product life cycles and the need to eliminate inventories. Some advantages of shorter and more efficient setups include flexible systems, shorter lead time, better quality, higher performance, and the opportunity to level the production schedule. Setups are therefore standardised, simpler and safer, for better production.

Shigeo Shingo developed an approach to reduce changeover time with the SMED concept that is based on the separation of internal and external setups. This simple, yet effective approach is summarised in three steps that form a repeated cycle. [38]

Step 1: Observe the process to separate internal setups and external setups; internal setups can only be performed when the process is stopped, but external setups can be performed while the process is still in operation. Therefore, focus on the reduction of external setup time through preparation of equipment before the start of the setup, the utilisation of the right people, and resources that are available when needed. This can be supported with basic checklists and functional checks on equipment and tools.

Step 2: Convert internal setups to external setups where possible to ensure that the maximum amount of preparation is accomplished before the process is stopped. This requires the analysis of every function in each internal setup, and the identification of opportunities to convert these into external setups. Conversion techniques include the standardisation of setups and preparation of changeover conditions in advance.

Step 3: Streamline internal and external setups through simplification. Take another look at every function within each setup and identify opportunities to avoid the need for adjustments, and ultimately eliminate the need for the setup. However, this is not always practical and often parallel functions are required to reduce setup time. After a setup is minimised, it should be monitored and maintained with standard visual controls.

3.4.7 Total productive maintenance

Total productive maintenance (TPM) aims to maximise the effectiveness of process equipment to achieve continuous flow and consistent performance. This technique relies on a combination of three strategic maintenance approaches that also aim to optimise equipment performance and minimise downtime. These approaches are preventative maintenance, simplified maintenance, and maintenance prevention. [60]

Table 3.4: Total productive maintenance strategies

Strategy	Description
Preventative Maintenance	The prevention of breakdowns by doing maintenance prior to failure
Simplified Maintenance	The simplification of maintenance to make it easier and safer
Maintenance Prevention	The design of equipment that requires little or no maintenance

TPM requires organisational wide cooperation between functions and processes, and does not only depend on a centralised maintenance department that has to serve every operation. This requires employee participation to ensure a safe environment with reliable equipment. Hazardous should also be evaluated in frequent intervals to avoid accidents, damage, or unexpected costs. This is supported with checklists, standardised operations, and the coordination of irregular maintenance activities.

Equipment effectiveness has a direct effect on workers and they should therefore be involved in data collection, loss identification, and problem solving. Process workers must be trained to take care of the equipment that they use and management must encourage preventative maintenance. Typical daily activities include basic repairs, equipment replacement, precision checks, and the identification of irregularities. This empowers workers with ownership of their equipment, and increases their moral. [35]

The ideal state would lead to equipment that always operates at maximum capacity without any defective output. However, this is not always practical, or even realistic, and should only serve as a visionary goal to strive towards. One important indicator that is often used to measure the performance of equipment is overall equipment effectiveness (OEE). This indicator is also used to track and monitor TPM activities.

Seiichi Nakajima introduced OEE as a fundamental TPM indicator in 1988 to create awareness of effective equipment utilisation. This indicator supports the identification, analysis, and reduction of equipment and process related losses. OEE is calculated as the product of the availability rate, the performance rate, and the quality rate. [61]

Availability rate is the actual amount of time that equipment is in operation versus the available time, also called load time. This refers to time when the equipment is not in operation, although it was scheduled to run; so load time does not include planned stops such as preventive maintenance and operator breaks. A low availability rate indicates downtime losses in terms of failures, slow setups, and material shortages.

Performance rate is the product of the amount of units produced and the theoretical cycle time per unit, versus the total actual operating time. This refers to equipment that does not always operate at the standard speed designed to control the specific process. A low performance rate reflects speed losses in terms of idle time, reduced speed operations, and unplanned stoppages; this does not include defective output.

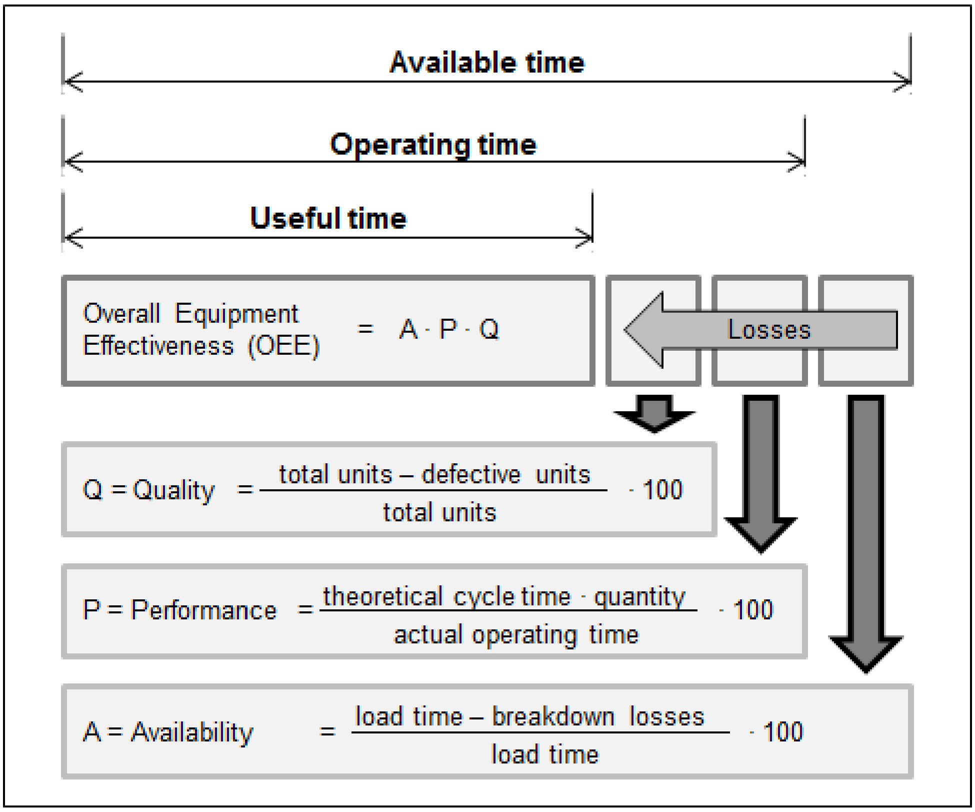


Figure 3.10: Overall equipment effectiveness

Quality rate is the ratio of good units versus the total amount of units produced. This refers to the portion of output that complies with a specified quality standard. A low quality rate indicates defect losses in terms of scrap, rework, and start-up problems.

These three factors are used for the identification and reduction of equipment losses to yield an OEE of 100%. However, this is not always a realistic target. Therefore, Seiichi Nakajima defined optimal values for each of the OEE factors that are realistic and achievable: an availability rate that surpasses 90%, a performance rate above 95%, and a quality rate that exceeds 99%, in order to ensure at least 85% OEE. [61]

3.4.8 Built-in-quality

Built-in-quality, also called Jidoka or autonomation, is the concept of "automation with a human touch" or "intelligent automation" to detect and prevent errors. This concept is one of the three pillars of the TPS frameworks because customer quality drives the value proposition of lean organisations. It is also an important part of flow because it focuses on small batch sizes to ease error detection and ensure quality and flexibility.

The dependence on continuous flow to connect operations increases the severity of any problem and necessitates their elimination. Built-in-quality systems emphasises equipment readiness, manpower availability and material supply when operational functions are stopped because of a failure. Although the traditional believe is that this is unacceptable, the counterintuitive thinking is an opportunity to identify a weakness within the system, to attack the weakness, and to strengthen the overall system. [62]

Principle 5: *Build a culture of stopping to fix problems, to get quality right the first time*

The concept of built-in-quality was introduced when the founder of Toyota, Sakichi Toyoda, developed the power loom after he watched his grandmother slave away at a manual loom. The problem with the manual loom was that if a single thread broke, material woven after this failure was wasted until the problem was detected and the loom was reorganised. Toyoda noticed this problem and his solution was to build the human capability into the loom to stop when a problem was detected. He achieved this with the andon system, which uses a signal to alert the operator that the loom needs assistance. This became the basis for one of the three pillars of the TPS. [16]

Built-in-quality is a five step approach that aims to detect problems, stop the process, fix or correct the immediate condition, investigate the root cause, and install a proper countermeasure. It reduces any adverse impact for the customer, as well as cost of a mistake because defects are removed before further value is added. Also, when the recurrence of a problem is prevented at the source as soon as it occurs, the process is improved in the long run even though the short term result may not be transparent.

Motivated people are at the centre of the TPS framework and this is also reflected in built-in-quality. Traditional organisations assume that mistakes are caused by human error, but lean organisations are aware that an error is caused by system failure; this means that errors occur because the current system allows them, and not because people are incompetent. Organisational wide participation is therefore required to create systems that prevent mistakes. This also includes the use of poka-yoke. [38]

Poka-yoke (error proofing) is any device or procedure that either prevents mistakes or makes mistakes apparent for elimination. The concept was developed by Shigeo Shingo in the 1960's. He pointed out that mistakes are bound to happen, but this can be prevented to some degree through the implementation of poka-yoke; the objective is to eliminate the root causes of conditions that introduce errors into the system. [63]

Poka-yoke is a typical lean technique that is used for the identification and evaluation of problems. It is a concept that is often demeaned because of its relative simplicity; this is a common problem with most lean ideas. However, poka-yoke is a relevant technique at locations where people are responsible for a process, because they can sometimes inadvertently forget important work practices and their performance varies.

A decent poka-yoke device should be simple and cost effective, part of the process, and able to provide quick feedback from where the error occurred. The feedback must ensure that an operation can be checked without the need for special attention from the process worker. Typical poka-yoke devices include checklists, automated measurements, temperature gauges, limit switches, colour codes, and warning lights.

Remember that advanced technology is pointless unless an effective problem solving method is implemented that supports the system. Successful built-in-quality systems call for extensive support structures that provide people with the resources required to detect and solve problems. This requires a trained and empowered workforce. [38]

3.5 Establish pull

In 1949 the president of Toyota, Kiichiro Toyoda, challenged his executive team to improve their production rate and avoid bankruptcy. Taiichi Ohno, vice president of Toyota, accepted this challenge and developed the pull system with the support of several other important Japanese industrial innovators such as Shigeo Shingo and Hiroyuki Hirano. They drew inspiration from the American supermarket structure that was able to quickly replace any product drawn from the shelves by the customer. [38]

Ohno and Shingo suggested a smooth system that delivers the right material, in the right quantity, with perfect quality, in the right place, when it is needed, as requested by the customer. They called their approach just-in-time (JIT) service provision. This production approach uses takt time, continuous process flow, and a pull system.

Principle 3: ***Use "pull" systems to avoid overproduction***

A pull system controls the flow of work through a process with the release of work into the system only when it is required because a product or service was requested by the customer. On the other hand, a push system releases work into the system as demand is predicted or as work becomes available. This can lead to high inventory, production chaos, firefighting, extended lead times, and lack of important resources.

There are several advantages to pull systems besides improved responsiveness to customer demand and prevention of excessive inventories. Additional advantages include shorter lead times, lower inventory storage costs, shorter time to detect errors and quality problems, lower risk of obsolescence, less transportation damage, lower material movement costs, lower space requirements, and shorter travel distance. [64]

Pull systems enable the production of what is needed, based on a signal of what has just been removed from an operation or process. This signal connects information throughout the system to minimise overproduction. Furthermore, the signal ensures continuous replenishment of work into the system. This signal is called kanban. [65]

Kanban is a Japanese word that stands for card (Kan) and signal (Ban). It is a visual control system at the point of control for inventory management. The aim of kanban is to reduce work in process through the frequent replenishment of small amounts of buffer material based on consumption. This system ensures that just enough material is available to produce what is required and protect the system against variation. [35]

Kanban is to pull systems what MRP is to push systems; but kanban is authorised by downstream operations to supply work. This signal is used most often in organisation where there is a stable demand and continuous process flow. Kanban devices should be easy to understand, simple and effective to visualise, and relatively easy to set up.

A kanban order can be communicated upstream through several different types of cards or visual signals. A basic card can be send upstream to indicate a required order. Some organisations have painted squares on the ground or workstations to signal an order if the square is empty. Sometime a container itself can be used as a signal device when it requires to be refilled. Coloured golf balls can even be rolled down a pipe to the replenishment centre to order replenishment of specific work. [38]

Even though inventory is standardised and controlled via kanbans, it does not lead to zero inventory systems. The challenge is therefore to reduce the number of kanbans to reduce the inventory buffer. This means that kanbans are a waste that should be eliminated over time if possible. Start to reduce kanban quantities to promote smaller batches. The number of kanbans required can be calculated with the formula below.

$$K = \frac{D \times L \times (1 + S)}{C}$$

Where:
K = number of kanban cards
D = average number of units demanded per period
L = lead time to replenish an order (expressed in the same time unit as demand)
S = safety stock expressed as a percentage of average demand
C = container size

Figure 3.11: Kanban calculation

3.6 Pursue perfection

The nature of continuous improvement means that after the successful completion of the process focus steps the cycle must be repeated with a more focused perspective that supports incremental improvement efforts. This is because lean ideas are based on incremental improvement activities to ensure a stable environment. Even though initial improvement activities were performed in sequence, lean actions must now be performed as one, because their influence is strong enough to affect each other. [66]

4. Theory of Constraints

Theory of constraints (TOC) is a continuous improvement methodology that aims to alleviate system constraints in order to ensure maximum operational throughput. This scientific approach is based on the assumption that every system consists of multiple dependent operations and one of these acts as a constraint to the entire system. [67]

The concept of TOC can be understood through the chain analogy: View the system as a chain of interdependent links that work together toward a common goal. Overall performance of the chain is governed by the strength of the weakest link. Therefore, any improvement that doesn't focus on the weakest link is considered to be wasteful.

One fortunate characteristic of TOC is that the current constraint, or weakest link, is also the highest priority, because TOC does inherent prioritisation of constraints. This focused methodology creates opportunities for rapid improvement efforts. Immediate results include faster process throughput, reduced inventory, and increased capacity.

Organisations with extensive hierarchical structures and centralised knowledge value TOC even more because activities can be localised with only a few people that have the authority to implement change. Intensive knowledge of data analysis is also not a requirement for this approach. Employees are therefore often excluded from problem analysis because their suggestions are not required for successful improvement. [68]

History of theory of constraints

In 1979 Eliyahu Goldratt, a trained physicist, introduced a software-based production scheduling approach known as *optimised production timetables*, changed in 1982 to *optimised production technology*. This approach was successful because of the logic that Goldratt introduced. He also realised that his analytic approach can have a much broader impact on performance than an improved production plan and schedule. [69]

In 1984, Goldratt used his Socratic way to introduce and teach TOC to the world with his popular novel, "The Goal". This management orientated novel provided context for a basic approach to continuous improvement. It discussed many of his constraint alleviation philosophies, but it didn't expand on the complete body of knowledge. [67]

Goldratt published “The Race” in 1986 to further develop his logical system and get concepts straight though illustrations and not in the form of a novel. This clarified the practical implication of how to implement solutions with the drum-buffer-rope method, based on metaphors developed in “The Goal”. This book also provided insight into throughput accounting with the brief introduction of *global operational measures*. [70]

Goldratt expanded his methodology in 1990 with his book “What is this thing called Theory of Constraints and how should it be implemented?” This book addressed the fundamental methods of the TOC thinking process to enable focused problem solving for any system. The five focusing steps of constrain alleviation is also discussed. [71]

Focus of this chapter

This report discusses TOC as a tactical roadmap, strategic roadmap, and accounting application. The tactical roadmap, five focusing steps, focuses on the alleviation of practical constraints. The strategic roadmap, thinking approach, is a logical approach towards systematic problem solving. Lastly, throughput accounting is a measurement system that prioritises and monitors improvement efforts to support these roadmaps.

4.1 Five focusing steps

The five focusing steps is a tactical roadmap that provides a structured approach to streamline complex processes through constraint alleviation and synchronisation of activities to achieve continuous improvement of process performance. This requires complete appreciation of the interrelated components that comprise the system. [71]

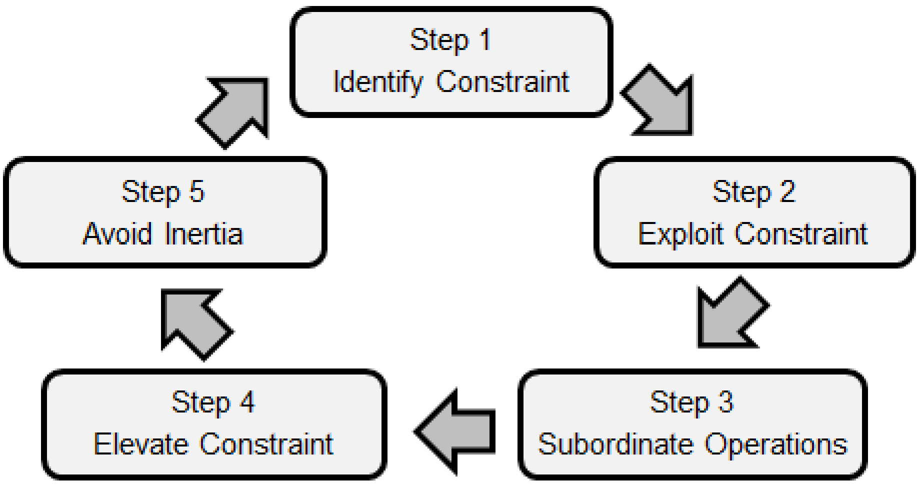


Figure 4.1: Five focusing steps of theory of constraints

4.1.1 Identify constraint

Modern organisations are so complex that almost an infinite number of improvement opportunities are available. However, TOC assumes that every system only has one immediate constraint that governs its performance. Identification of this constraint is therefore crucial to streamline complex systems and prioritise improvement activities; the capacity constraint is also called the bottleneck because it limits the flow of work.

The tactical roadmap, five focusing steps, is utilised for the alleviation of physical process constraints. These can be categorised as either external or internal. External constraints can be located at the vendor if material or information is not available to produce what the customer demands; external constraints can also be located in the market if production capacity exceeds consumption. Internal constraints are located in the organisation because of operations with limited capacity that govern flow. [52]

Several approaches can be used for the identification of internal constraints. A simple technique, also an important lean principle, is the direct observation of the process to thoroughly understand the actual situation at process level. First, look for excess WIP because inventory often accumulates before the immediate constraint. Then, look for operations that often need to be expedited to complete important orders on time. [67]

Time spend at process level also promotes an appreciation of individual operations because of interactions with process workers. This is also an effective way to gather more information from workers to get their opinion on where demand of an operation exceeds its capacity. Then focus on that area, but also look for other constraints.

Another basic approach is to evaluate every operation to find the one with the longest lead time. Use a flowchart or lean VSM to document the process in detail so that it is easier to evaluate individual operations. This also encourages employee participation to exploit their knowledge through the application of idea generation techniques. [52]

The identified constraint is also known as the drum in the renowned drum-buffer-rope method. The drum title is implied because the constraint provides a beat (cycle time) to which other operations can be synchronised. TOC states that an hour lost at the constraint is an hour lost for the total system. Therefore, initial improvement activities should support the constraint to operate at or near full capacity. The buffer and the rope are discussed later when the drum is understood, exploited, and improved. [72]

4.1.2 Exploit constraint

The inherent prioritisation of TOC drives the alleviation of the constraint identified in the previous step. Improvement activities should aim to overcome the limitations and restrictions caused by this constraint. This can be achieved with several approaches that intend to decrease the workload or increase the throughput of the constraint. [67]

Decrease the workload of the constraint with an improved production schedule. First, prioritise the work that the constraint needs to perform. Second, ensure that input to the constraint is free of defects. Third, share work that can be performed by other operations; even if these operations are less efficient, the workload of the constraint is reduced and the improved system throughput is expected to be more profitable.

Increase the throughput of the constraint with more efficient practices. First, assign the most productive worker and technology to the constraint. Second, train several workers in the skills required for constraint operation to guarantee that the required skills are always available for a functional constraint. Third, use visual management to make the constraint more transparent and implement standardised best practices.

Whichever exploitation approach is executed, the focus should be on quick wins and rapid relief without the need for invests in additional and expensive resources; only current, available resources should therefore be used. This can be as simple as the distribution of information so that employees can pay more attention to the constraint.

Once the constraint is exploited, use regular audits to ensure that it functions when it should and that it produces defect free work. Also ensure that an appropriate size of work is available in front of the constraint to avoid starvation; this means that the constraint has enough resources available and idle time is eliminated. However, if the constraint moved because of exploitation activities restart the five focusing steps to determine where the new constraint is located and plan new alleviation activities. [35]

4.1.3 Subordinate operations

The focus of this step is the subordination of other operations, the non-constraints, to support the needs of the constraint. This is possible because TOC states that only one operation is the immediate constraint, which means that other operations have some amount of excess capacity. These operations are therefore more flexible and must be used to ensure process flow and continuous operation of the constraint. [72]

The drum-buffer-rope method is used to regulate process flow through the capacity constraint. Non-constraints are subordinated with the current operational rate of the constraint to achieve optimum flow and minimise WIP inventory. Remember that the *drum* provides the beat (cycle time) that serves as the foundation for subordination.

The *buffer* is measured in units of time to determine the appropriate time for material release. Material is then released into the system at fixed time intervals to arrive at the constraint some period of time prior to its scheduled start. This specified period of time, the buffer, is used to protect the constraint from starvation because of upstream variation. The size of the buffer is therefore also dependent on process variation. [73]

The challenge with the buffer is to maintain a safe level of work to avoid starvation, without the creation of large amounts of inventories. Only the required amount of material is therefore released into the process. However, some organisations also maintain a physical buffer in front of the constraint and in front of the final customer to deal with breakdowns, process variation, lack of resources, and demand fluctuations.

The *rope* is a signal generated when the constraint receives a work order. Once the customer placed an order, the rope triggers the release of material into the process at a certain time dictated by the buffer. Material can be released earlier than required, with a larger time buffer, to compensate for high process variation. This subordinated release schedule guarantees flow without the accumulation of excess inventory. [73]

Remember, this approach is used to release material into the system, at fixed time intervals, with an equal amount of work as required by the constraint. It creates an unbalanced system, which allows non-constraints to ensure smooth operation of the constraint even in a system with high variation and product mixes. This approach is opposite to the balanced inventory based (kanban) system used to create lean flow.

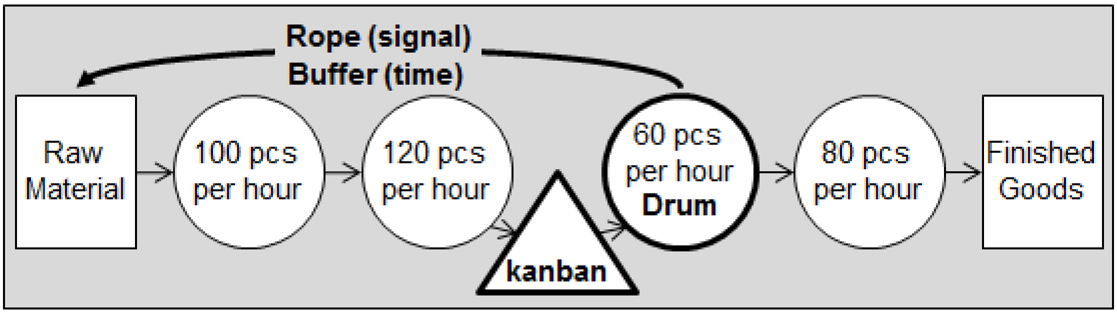


Figure 4.2: Drum-buffer-rope method with a kanban buffer

4.1.4 Elevate constraint

The objective of this step is almost the same as for constraint exploitation. However, constraint elevation focuses on more complex and substantive improvements. These improvements must continue to decrease workload or increase throughput until the constraint is removed. Therefore, larger investments in resources are often required.

Several lean practices are often effective when applied for constraint elevation. First, manage and maintain the constraint with TPM to decrease failures, breakdowns, and idle time that results from a poor maintenance schedule. Second, evaluate constraint changeovers with the SMED approach to minimise the loss of production time that is caused by inefficient changeovers. Third, build quality into the constraint with partial automation and poka-yoke to ensure defect free output. These practices can also be used to exploit constraints, but an investment in time makes them more effective. [52]

Evaluate current resources for constraint elevation if the lean practices were not able to eliminate the constraint. Consider the execution of additional shifts to increase the utilisation and throughput of the constraint. As soon as the constraint is efficient and operates at maximum utilisation with the current resources, but demand is still higher that its capacity, it may be necessary to employ more workers or purchase additional resources. Another option is to outsource some work to decrease the workload. [67]

Investments that are made in this step must be evaluated to determine their effect on process performance. Therefore, performance data should be analysed to determine the need for investment, and how it will benefit the organisation as a whole. OEE is a direct indicator of the effectiveness of the constraint and should therefore be used to evaluate the current state of the constraint and how it can be improved. Furthermore, use throughput accounting to determine the effect on system wide performance. [74]

4.1.5 Avoid inertia

The nature of continuous improvement indicates that the five focusing steps must be implemented as a cycle instead of a once of project. TOC is not completed after the alleviation of the constraint because of the assumption that there is at all times one operation in the system that acts as the constraint. Therefore, the cycle is repeated to discover and alleviate the new constraint. Furthermore, remember that the alleviated constraint must be supported with a possible change in rules, policies, and priorities.

4.2 The thinking process

The thinking process is a strategic roadmap that applies cause-and-effect logic to understand the core conflict (problem) in processes with many interdependencies. It is used to analyse the current state, identify the core conflict, and develop an action plan to reach an improved future state. This approach guarantees that improvements do not focus on the treatment of symptoms, but rather the elimination of root causes.

A suit of logic diagrams, also known as tactic trees, provides guidance throughput the thinking process. These logic diagrams form the central part of the roadmap and aim to optimise the performance of the entire organisation instead of individual function in isolation. This approach is convenient for everyday problem solving because it is able to deal with intangible constraints such as policies, paradigms, and behaviours. [75]

The tactic trees require different types of logical thinking to accomplish their purpose: sufficient cause and necessary condition. Sufficient cause thinking uses a cause and effect approach based on the assumption that the existence of something is sufficient to cause the existence of something else. Necessary condition thinking is based on requirements, which means that something must exist for something else to exist. [76]

Table 4.1: Classification of the five tactic trees

<table>
<tr><th>Logic
Questions</th><th>Sufficient cause</th><th>Necessary condition</th></tr>
<tr><td>What to change?</td><td>Current reality tree</td><td rowspan="2">Evaporating cloud</td></tr>
<tr><td>What to change to?</td><td>Future reality tree</td></tr>
<tr><td>How to cause change?</td><td>Transition tree</td><td>Prerequisite tree</td></tr>
</table>

4.2.1 Current reality tree

The current reality tree (CRT) is a logical structure which represents the current state of a process in terms of the most probable chain of cause and effect conditions that lead to the core conflicts. This provides the motivation for the need to improve. The undesirable effects (UDEs) are identified and traced back to their root causes, which are identified as the constraints that are responsible for most of the current conflicts.

CRT is an effective tool to determine where to start with improvement efforts when faced with a long list of problems. The structure also makes problems transparent and this helps to identify behavioural patterns of conditions that exist in the current system. This process starts with a set of UDEs, and builds down to the root causes, which require the development of a solution. These steps are discussed below. [77]

Step 1: Determine the scope of the analysis; Define the goal and boundaries of the system, together with its inputs and outputs. Then define the measures of success that will be used to monitor and track the progress of improvement activities. Include people in this process from different function areas, which understand the purpose of a CTR, so that analysis and evaluation of the process reflects the system as a whole.

Step 2: List between 5 and 10 pertinent UDEs. These are the entities that cause the most problems in the system. They should provide real evidence of misalignment in system objectives or an indication of possible system restriction. The descriptions of these UDEs must be clear to each stakeholder and their actual existence should be uncontroversial. This provides the foundation for further analysis toward root causes.

Step 3: Connect the pertinent entities that appear to be involved in a sufficient cause relationship. This includes relationships in which one pertinent entity is a cause for another pertinent entity (linear connection), or a relationship in which an additional, common cause is identified for two or more of the pertinent entities ("V" connection).

Step 4: Connect multiple necessary condition entities required for a single entity with an AND connection. Additional entities may be required when an individual cause is necessary, but not sufficient by itself to cause an effect. These are joint by an AND junction, which is represented by an oval, to indicate sufficiency. However, avoid the used of extra entities unless it is required to connect a pertinent UDE to the tree. [76]

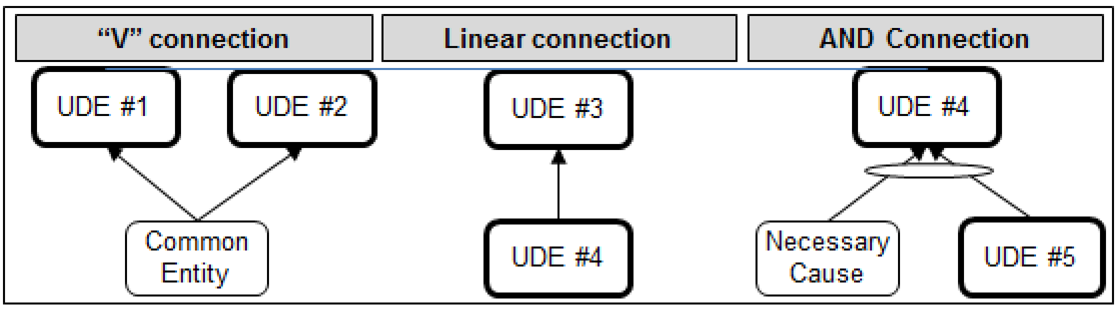


Figure 4.3: Types of tactic tree connections

Step 5: Finalise construction of the tree. At this stage there may be several clusters or entities that are not connected. Develop and add intermediate effects that tie two or more clusters or entities together. Also look for and connect UDEs at a higher level that aggravates UDEs at a lower level with negative reinforcement loops. Continue to connect the entities from causes to effects until all entities are connected. Note that entities without predecessors are called entry points and represents the root causes.

Step 6: Review and revise the CRT for completeness. Use this opportunity to expand the tree to better understand the current state of the process. Also look for additional UDEs and absent connections that exist between entities. Read and verify the tree from each entry point; begin with the lowest point, and determine if the tree provides a clear reflection of the current situation with the appropriate assumptions and logic.

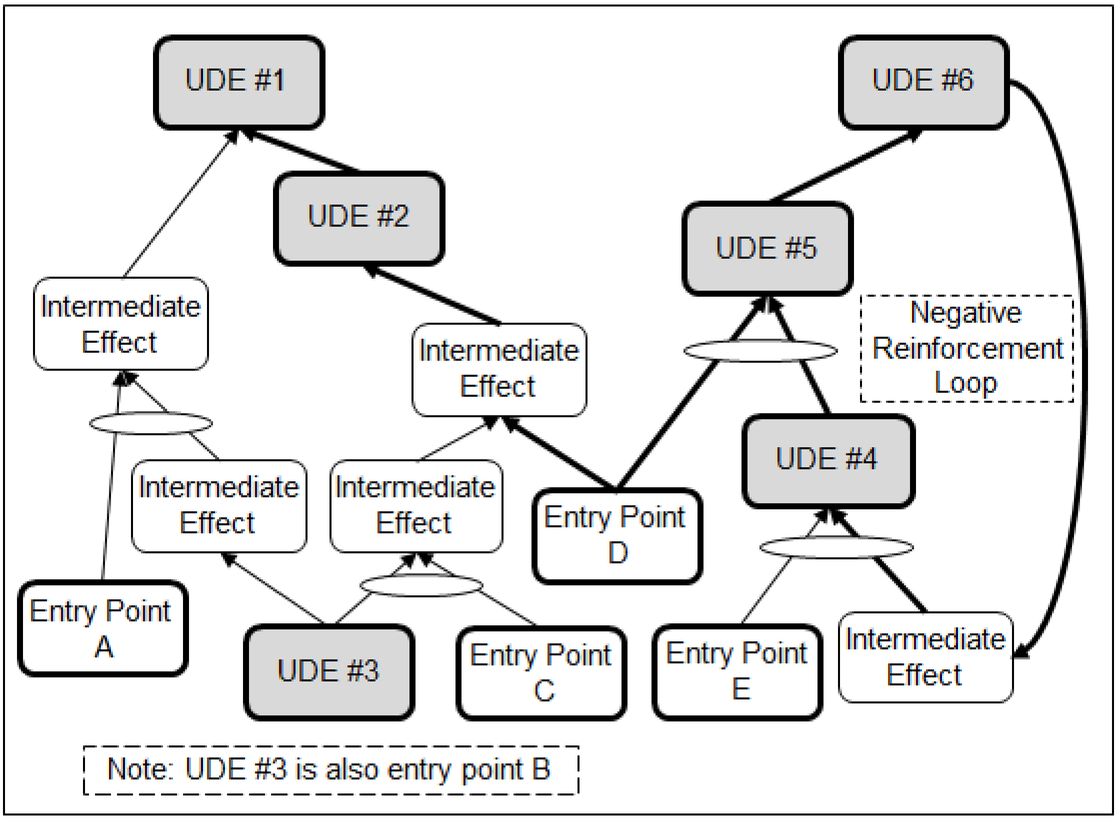


Figure 4.4: Current reality tree

Step 7: Determine the core problems of the studied system. Calculate the percentage of UDEs caused by each entry point; divide the sum of the UDEs that exist on every path that leads from an entry point with the total number of UDEs in the process to determine the core problems. These are defined as entry points that are responsible for more than 80% of total UDEs; Table 4.2 provides an example based on Figure 4.4.

Table 4.2: Current reality tree evaluation

		Undesirable Effects							
		1	2	3	4	5	6	Total	%
Entry Points	A	X	–	–	–	–	–	1	17%
	B	X	X	X	–	–	–	3	50%
	C	X	X	–	–	–	–	2	33%
	D	**X**	**X**	**–**	**X**	**X**	**X**	**5**	**83%**
	E	–	–	–	X	X	X	3	50%

From Table 4.2, it is clear that Entity D is the core problem, because it leads to more than 80% of the pertinent UDEs. When no entity is responsible for more than 80% of the pertinent entities, it is necessary to look for a common cause for one or more of the entry points to the tree. Always double check the answer and envision the CRT without the core problems. The next step is to solve the identified core problems. [78]

4.2.2 Evaporating cloud

The evaporating cloud (EC), also called conflict resolution diagram, is an analytical approach used to achieve mutual consensus in search of a plausible solution to the inherent conflict of the core problem, which is the output of the CRT. This focuses on the development of future conditions or actions that aim to overcome any inherent assumptions that prevent the achievement of a specific organisational objective. [77]

Unlike the other tactic trees, the EC has a fixed format that includes two entities that are defined as opposite wants, which represent the conflict, the need that each want satisfies based on assumptions, and a common objective that requires both needs to be satisfied. The EC template is displayed below, followed by its construction steps.

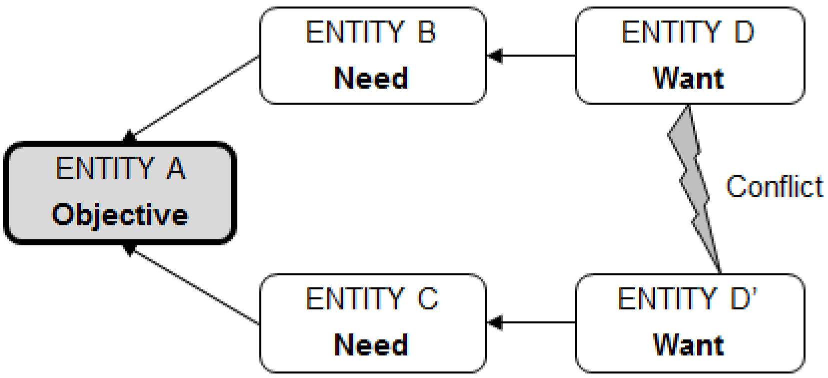


Figure 4.5: Evaporating cloud

Step 1: Identify the wants. Entity D is the core problem copied from the CRT, and Entity D' is then the opposite of the core problem. These entities are prerequisites to entities B and C, but cannot coexist because they are in conflict with each other.

Step 2: Identify the fundamental needs. Entity B represents the need that is achieved with the existence of Entity D; Entity C represents the need the will be achieved when Entity D' exists. However, both B and C are requirements toward the achievement of a common objective; despite the fact that D and D' cannot exist at the same time.

Step 3: Identify the organisational objective. Create a single objective entity that is a successor of both needs. If there is no common objective, then there is indeed no real conflict. Therefore, if a common objective exists, it cannot be achieved at present because of conflict between the prerequisites. Current policies and paradigms are therefore most likely some sort of compromise between the two entities that conflict.

Step 4: Ensure that the diagram is sensible. Use necessary condition logic to read the diagram form left to right. This method validates the necessity of each entity that is a predecessor to another entity. Use this opportunity to fix or clarify the description of each entity so that everyone affected by the process understand it the same way.

Step 5: Review and validate the assumptions. Each arrow is based on one or more assumptions that determine why a need or a want must be present to achieve its successor entity. There are also assumptions that underlie the conflict between the apparent mutual exclusive entities. These assumptions can either be valid or invalid.

When every assumption between two entities is considered invalid, the necessary condition relationship between them is also eliminated. If the assumptions between the two wants are considered invalid, then the perception of conflict is false and it doesn't even exist. Either of these cases establishes that there is no real conflict situation in the system and a viable path is identified out of this illusion of conflict. [76]

Step 6: Brainstorm injections when conflict is still present. An injection is any action that will enable the achievement of an objective of a necessary condition relationship without the current necessary condition. This includes actions that aim to eliminate assumptions that support the conflict between mutual exclusive entities. The goal is to find a path out of the conflict with the same approach that was used in the previous step.

Step 7: Choose one or more simple and practical injections through consensus that can be implemented to solve the core problem and improve the system. The selected injections must then be supported with the appropriate resources. Don't let possible implementation obstacles restrict the selection of certain injections because a future reality tree and a prerequisite tree can be constructed to deal with those issues. [78]

4.2.3 Future reality tree

The future reality tree (FRT) is a diagram that represents the future state of a system, which is achieved with the implementation of injections that are designed to eliminate or reduce UDEs. Its purpose is to ensure the proposed solution will in fact resolve the unwanted system conditions without the creation of new problems. This also requires the consideration and incorporation of negative outcome scenarios into the tree. [77]

A well-defined FRT provides the opportunity to review the effectiveness of ideas in theory before implementation, and also to brainstorm solutions to possible negative outcomes. This is better than fire fighting, when emergency solutions are required in reaction to unforeseen problems. The FRT begins with an injection, and then builds upwards toward a set of desirable effects (DEs). This process is discussed below. [78]

Step 1: Define the injection that is selected for implementation. This injection may be the result of a previous developed EC, a brainstorming session, or simply an idea or suggestion. Then create a rectangular entity that represent the injection and describe it in present tense for a better perspective. This provides the motivation for the FRT.

Step 2: List the anticipated objectives of the injection. These represent the DEs that summarise the preferred outcome; the objectives can simply be the opposite of the identified UDEs from the CRT. Then state each DE as a separate objective even if some of them seem unachieved. This provides the vision toward which to aspire.

Step 3: List potential undesirable conditions (negative branches) of the injection, this is known as negative branch reservation. UDEs from the CRT can often be used as negative branches; also, ensure that the selected injection itself is not an undesirable condition. These are not the same as obstacles, which are defined as difficulties in the implementation of injections; obstacles can be put aside for the prerequisite tree.

Step 4: Connect the injection to the objectives. Make use of sufficient cause thinking to connect one objective at a time to the tree. Additional intermediate entities and current entities from the CRT can be used to achieve any necessary conditions that are needed to achieve the desired objectives. Each necessary condition, also known as an AND relationship, is indicated with an oval that connects two or more arrows.

Continue until each objective is connected to the tree. When this process starts to become inert, consider additional injections to satisfy necessary conditions. Add any significant DEs that can result because of the new injection. However, it is important to remember that the addition of new injections can also cause a new set of UDEs.

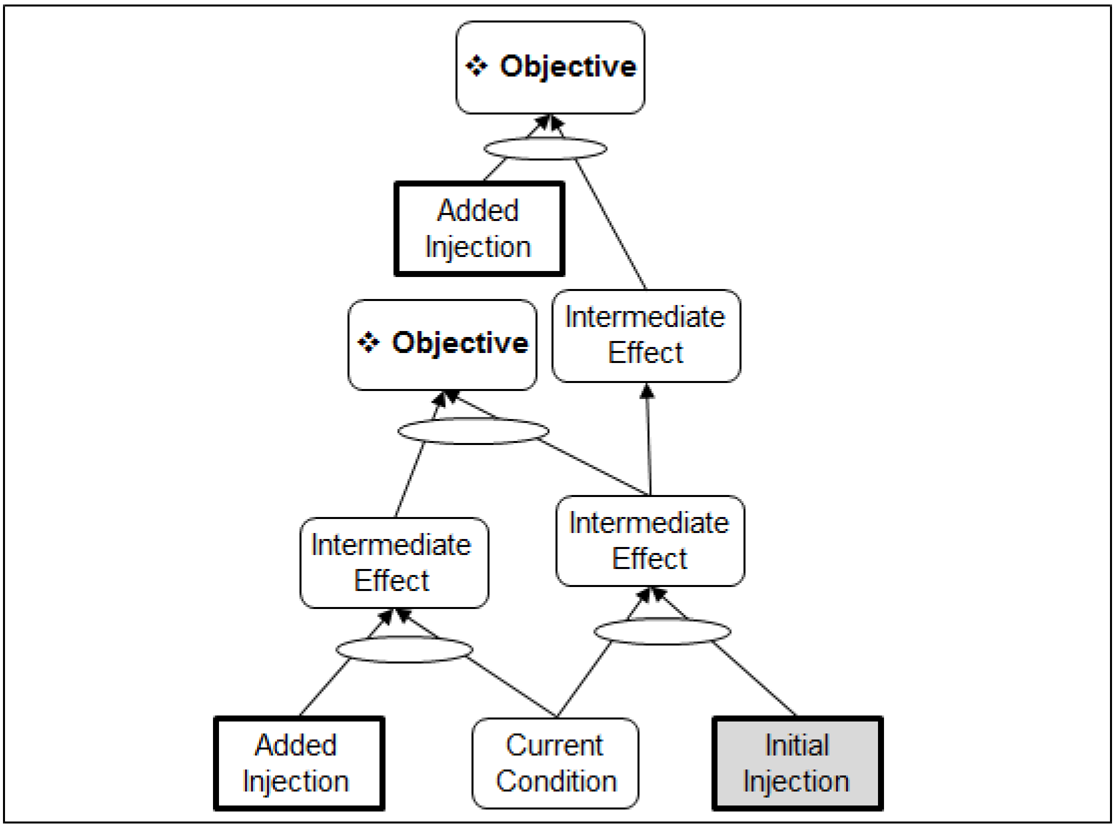


Figure 4.6: Future reality tree without negative branches

Step 5: Connect potential undesirable conditions (negative branches) to the tree. Use the same logic as in the previous step to connect potential UDEs one at a time; the connections where UDEs appear are the actual negative branches. Expand these branches with enough detail to get a clear image of how they affect the process. This also helps to understand why some injections are responsible for negative branches.

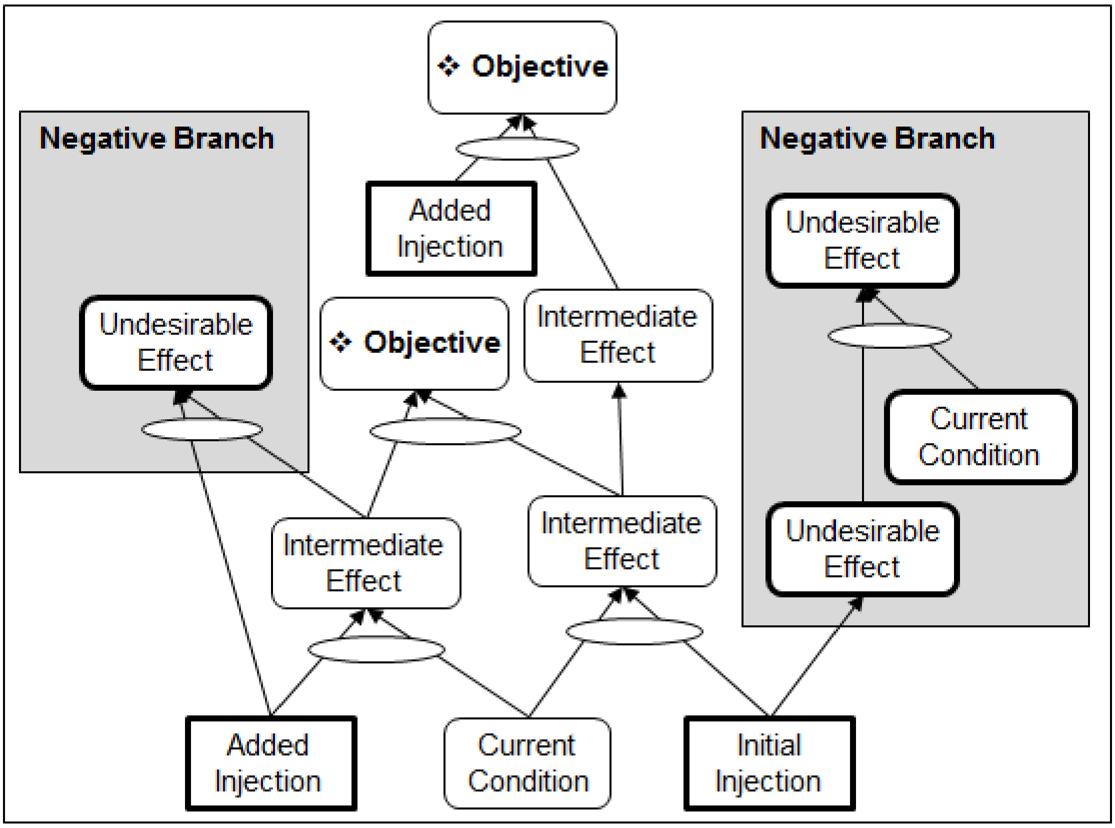


Figure 4.7: Future reality tree with negative branches

Step 6: Address the negative branches. Manage them with either reactive mitigation or proactive avoidance. Reactive mitigation means that new injection are paired with the UDEs, together with other entities if required, to cause neutral or positive effects that work against the UDEs. On the other hand, proactive avoidance means that alternative injections are develop to avoid the presence of entities that cause UDEs.

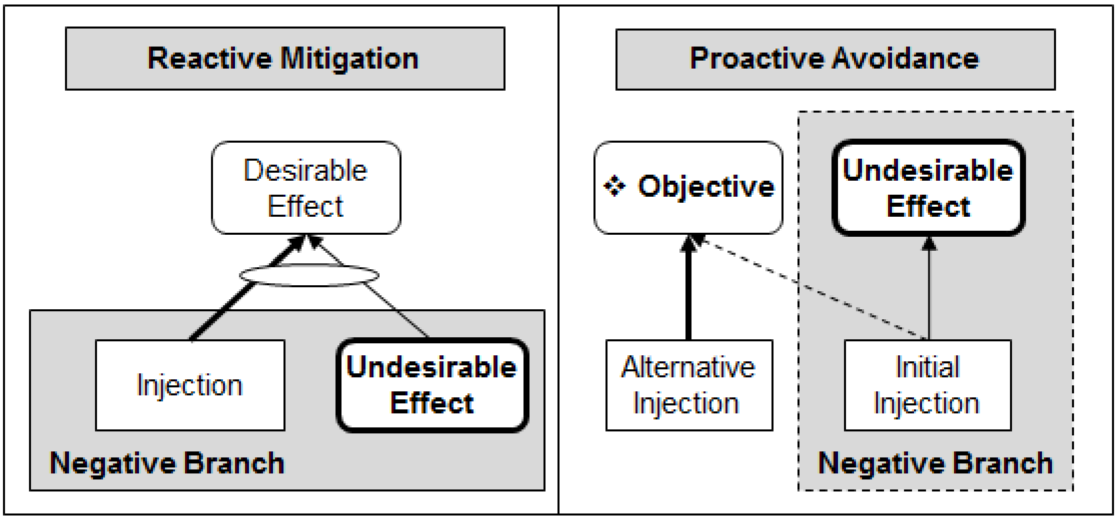


Figure 4.8: Mitigation and avoidance of negative branches

Step 7: Build positive reinforcement loops into the tree. Look for DEs that intensify the effects of entities lower in the tree that lead back to one or more DEs. These positive loops can help to create a self-sustained solution that supports continuous improvement. Additional injections or entities can also be implemented in order to satisfy the necessary conditions needed to create more positive reinforcement loops.

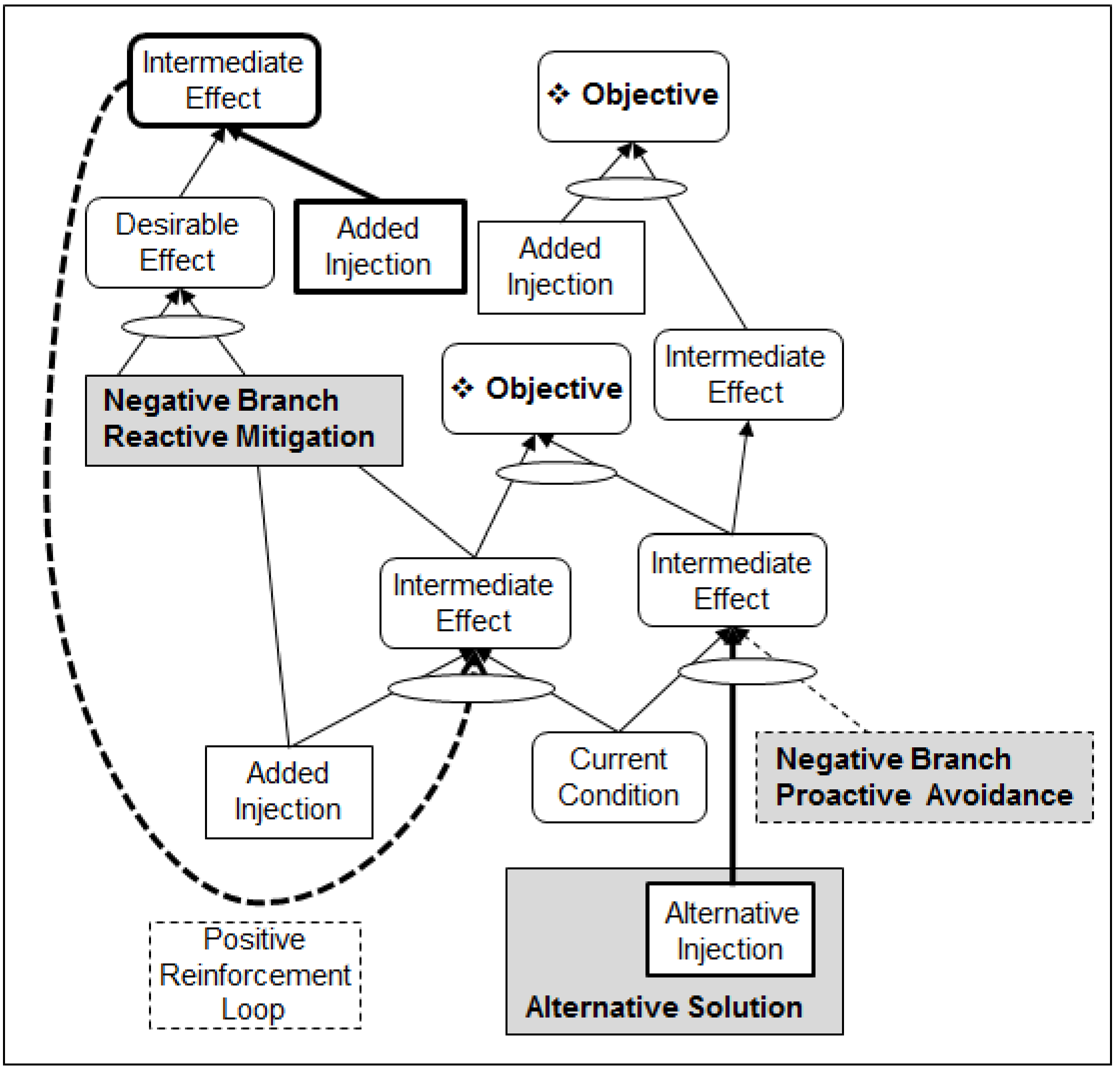


Figure 4.9: Future reality tree with a positive reinforcement loop

The FRT is completed once the potential positive reinforcement loops are identified and implemented into the tree. Once this is done it is sensible to review the tree and confirm that it reflects the desired future state. Thereafter, implement the injections in the actual system. However, there can still be obstacles that restrict their effective implementation; the prerequisite tree must be used to deal with those obstacles. [76]

4.2.4 Prerequisite tree

The prerequisite tree (PRT) is used to describe the necessary condition relationships that are required for implementation of injections. This is an effective tool to develop an implementation roadmap to overcome obstacles that are associated with complex solutions and procedures. The goal is to establish intermediate objectives that deal with these complex obstacles. The steps to create the PRT are discussed below. [78]

Step 1: Define the objectives. These are entities that describe the goal of the PRT and can represent injections that were identified in the EC or FRT. It is important to select organisational wide objectives to avoid suboptimisation. Use present tense for clear descriptions that communicate the desired outcomes to all the affected people.

Step 2: List the obstacles to overcome. Obstacles are current condition entities that represent the non-existent conditions that are required to achieve objectives. Once these obstacles are identified each of them should be evaluated to determine their presence in the system and how this presence prevents the achievement of objectives.

Step 3: Brainstorm intermediate objectives to overcome obstacles. These objectives are represented by milestone entities that must be satisfied in order to achieve the final objectives. Obstacles can be overcome in one of two ways. First, eliminate the obstacle completely. Second, eliminate the relevance of the obstacle to the objective.

Step 4: Map the implementation sequence of the milestone entities. Start with two milestones that appear to be associated with each other and connect them with an arrow to indicate a necessary condition relationship; the assumption behind each association is the obstacle, which is represented as an obstacle entity. Continue to connect the milestones to overcome the obstacles until each milestone is connected.

Step 5: Use the objectives that appear to be the most difficult to achieve as the basis for the PRT, so that it is easier to connect clusters, single entities, and objectives. It is also possible for some objectives to be milestones for other objectives. Furthermore, milestones established for an objective may also be used to achieve other objectives.

Connect the obstacles, which the milestones overcome, to objectives. Establish the associations between obstacles and objectives to form and attach new clusters to the tree. Connect the milestones that have no necessary dependencies, with any cluster.

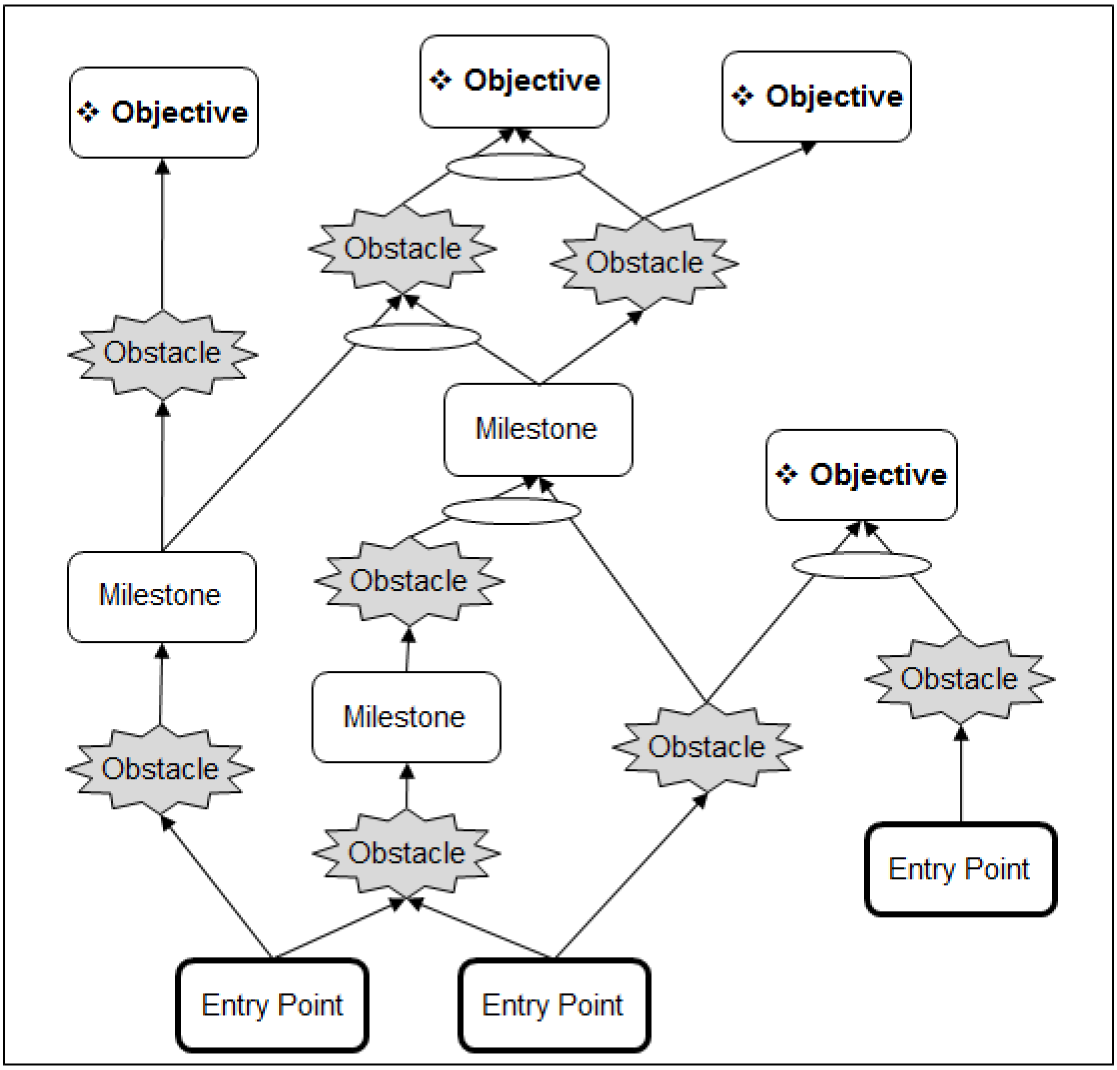


Figure 4.10: Prerequisite tree

Step 6: At this point all entities must be connected. Ensure that each entry point is practical and realistic. Consider obstacles that can present themselves when these entry points are implemented. Create new milestone entities for each new obstacle that is identified and connect them to a suitable entry point. Continue to deepen the tree until it feels well connected with entry points that entail no significant obstacles.

Step 7: Plan for implementation. Consider the resources required to accomplish each intermediate objective and make them available when required. This is important to ensure that implementation activities are performed as planned and that the desired results are achieved. However, a transition tree is often needed to develop a detailed action plan to determine the actions required to achieve intermediate objectives. [76]

4.2.5 Transition tree

The transition tree (TT) provides a final implementation plan to determine the actions required to implement the selected improvement ideas. This is almost the same as a project management tool that provides detail on how to move from the current state to the desired future state. The TT is also effective when used in high risk situations because it also applies negative branch reservation to every action, just like the FRT.

The development of a TT also provides a shared vision statement to communicate and rationalise improvement activities. This is crucial to obtain the commitment from people that are needed for successful implementation, but are not part of the team that created the initiative. The procedure to construct the TT is discussed below. [78]

Step 1: Define the objectives; it is important to create the implementation plan with the end in mind. This provides a shared purpose to work towards. The objectives can be direct copies of the injections from a FRT or intermediate objectives taken from a PRT. One objective is adequate for the TT, but it is also reasonable to have several related objectives. Then describe and document these objectives in the present tense.

Step 2: Determine the entry points to the implementation plan. This requires that the current environment is considered from the point where implementation is planned to be executed. This environment is represented with current condition entities that can be used as entry point for the execution of improvement activities. Only a few entry points are needed at first because more will surface when the TT is further developed.

Step 3: Create an action (injection) in order to move towards the objective through the achievement of intermediate objectives. Actions are entities that can be assigned to resources that have the influence to execute them. These must be defined with clear success criteria so that improvement activities can be monitored and evaluated.

Step 4: Determine connections between entities. This includes connections between current condition entities, actions, and the objectives that are expected to result from these actions. The current conditions and actions must be combined with sufficient thinking to achieve logical outcomes. If an outcome is an intermediate effect it must be combined with another action to move towards achievement of the final objective.

Step 5: Continue to build the tree until all the entities are connected and objectives are reached. Additional intermediate effects, which represent milestones that must be completed to achieve the objectives, can sometimes be required. These milestones are achieved through the combination of actions with current condition entities or with intermediate effect entities. This approach is also used with sufficient cause thinking.

The intermediate effect entities can be copied from the previous PRT. These entities are necessary conditions because a PRT is used to overcome obstacles and identify entities that do not exist in the current situation. However, these intermediate entities are probably not sufficient on their own to achieve the milestones and objectives.

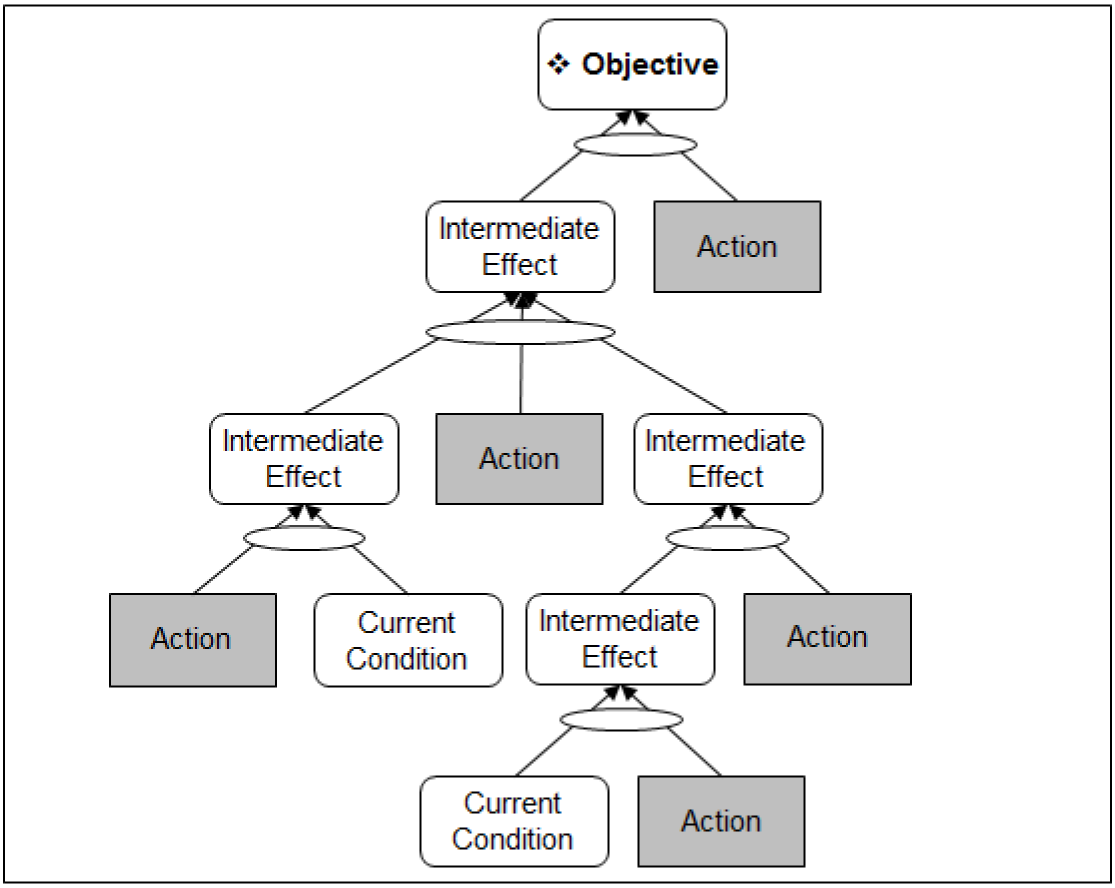


Figure 4.11: Transition tree without negative branches

Step 6: Address the undesirable conditions. This step is somewhat similar to how negative branch reservations are approach in a FRT. The difference is that in a FRT the negative branches start with injections and end with the desired conditions, while a TT starts with desired conditions (objectives) and works back toward the required injections. Actions copied from a FRT are therefore already designed to avoid UDEs.

Develop alternative actions for every negative branch to mitigate the UDE (reactive approach) or to avoid the UDE (proactive approach) altogether. The detail required for negative branch reservations depends on the level of risk involved. Execution of the TT can continue once the objectives are achieved without the existence of UDEs.

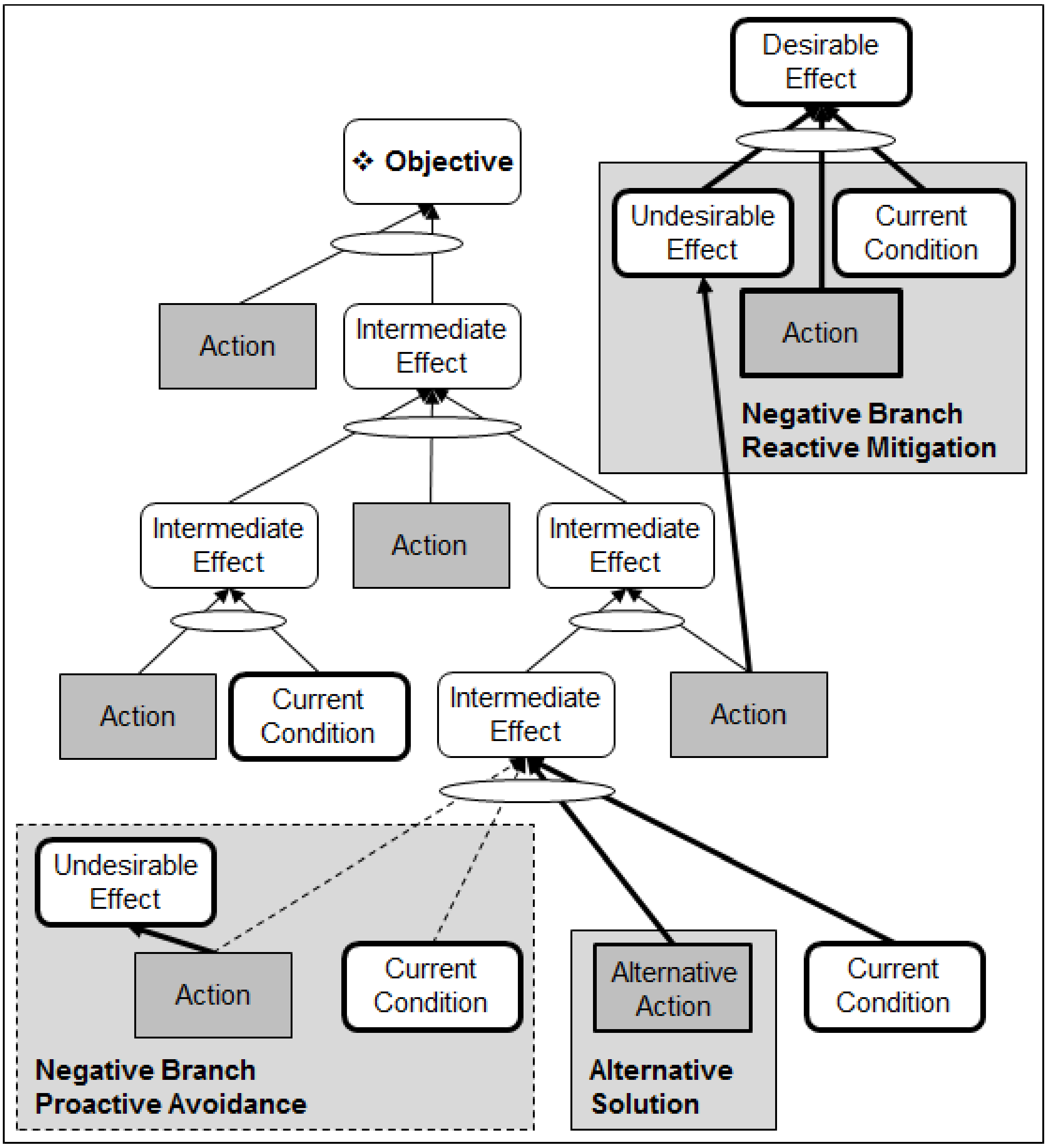


Figure 4.12: Mitigation and avoidance of negative branches (Transition tree)

Step 7: Execute the improvement plan. This requires the support of management and an empowered workforce. Review the tree to ensure that the entities are well defined for clear communication of the implementation sequence and the desired outcomes for each action. Then assign these actions to people that are able to influence and implement them. The TT can then be used to track and evaluate execution progress.

4.3 Throughput accounting

Throughput accounting is the TOC application for a holistic accounting approach that focuses on simplicity rather than complexity. This requires operational measures to evaluate performance of the system as a whole. It is also used to support everyday operations and to improve the quality of strategic decisions with regards to internal processes. The purpose is to increase total net profit by means of improved system throughput, but this approach challenges the principles of traditional cost accounting.

Traditional cost accounting is based on full absorption and it is a technical approach designed to satisfy Generally Accepted Accounting Principles (GAAP). It focuses on conventional measurements such as net profit, return on investment (ROI), and cash flow. These retrospective measures do not enable effective judgment of the current and future impact of decisions because of the way in which they are calculated. [74]

A problem with cost accounting is that it encourages overproduction because of its reliance on efficiencies and pressure for higher utilisation of resources. The excess inventory has a counterintuitive effect on income because inventory is considered an asset. But this creates a perceived profit based on inventory that may not be sold or become obsolete. It also ties up capital that can be used to generate actual income.

Another problem with cost accounting as that it puts an extreme amount of emphasis on cost reduction activities, which can have a negative impact on capacity. This is because almost all costs are allocated to operating expenses, which primary goal is to enable and support the organisation to produce throughput. The result is that profit growth is limited because improvements focus on a finite pool of expenses; rather focus on throughput because it provides, in theory, unlimited potential for growth. [79]

4.3.1 Basic measures

Dr. Eliyahu Goldratt identified throughput, investment, and operating expense as the three basic measures that can be applied across organisational functions to monitor improvement efforts. These measures provide a common language that influences the behaviour and priorities of organisational resources by rejecting the reliance on efficiencies, which it sees as counterproductive. They also establish a connection with traditional financial measures to support strategic and operational decisions. [80]

Throughput is the rate at which the system generates money through sales; this can also be expressed as the value that the system adds to the products or services that customers demand and purchase. Throughput is calculated as the sales, less the total variable cost in a given time period. This cost includes material cost and direct expenses such as commissions, customs duties, and external logistic services. [74]

This measure is characterised by both magnitude and speed. That means it focuses both on the difference between sales price and total variable cost, and also the time between process expenditures and income received. Improvement with regards to any of these characteristics has a positive and direct influence on ROI and cash flow.

It is crucial to understand how throughput accounting categorises labour and finished goods inventory. First, labour is not considered a variable cost unless it completely depends on the amount of output produced, because organisations do not regularly adjust the workforce every time demand fluctuates. Second, finished goods inventory is not considered throughput because it has not yet generated money through sales.

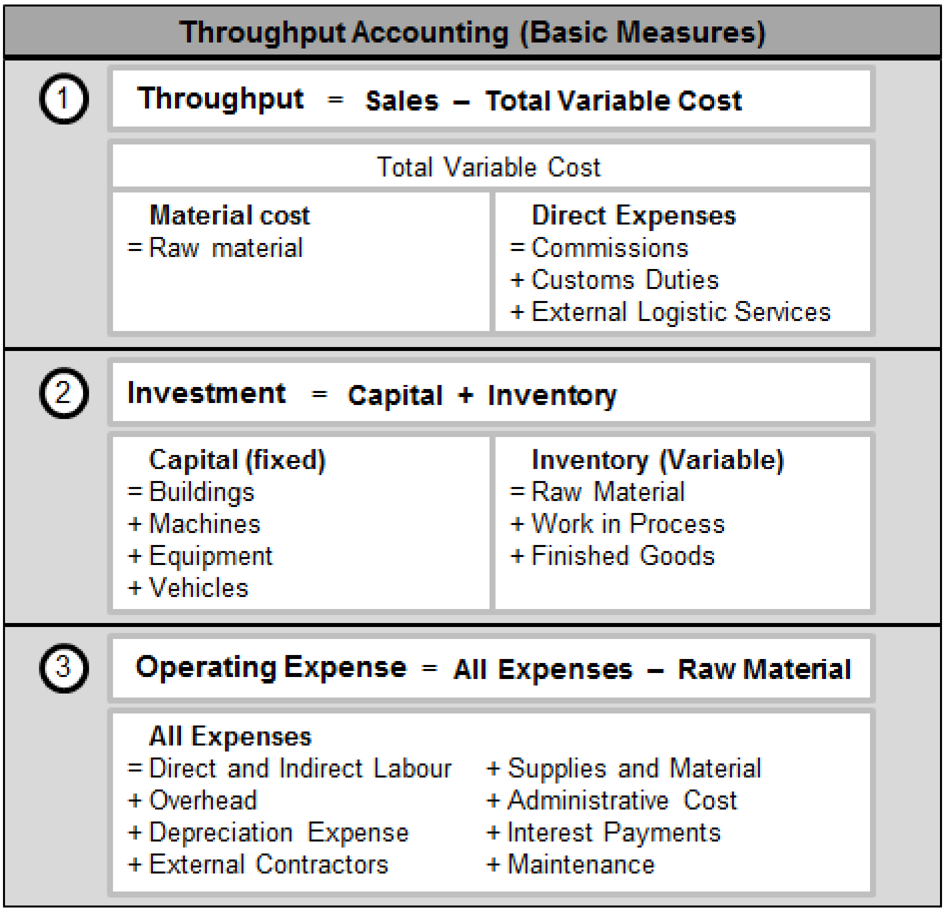


Figure 4.13: Throughput accounting: Basic measures

Investment is defined as the money that the system invests in capital and inventory to generate throughput. Capital investments include fixed assets such as equipment, machines, buildings, and vehicles. On the other hand, inventory investments include variable resources that comprise raw material, work in process, and finished goods.

Inventory investments only consider the total variable inputs that are purchased from external vendors and used in the system to produce throughput. Therefore, value added to the system in terms of direct and indirect labour is not considered part of inventory. Allocated cost, such as overhead, is also ignored for this calculation. [78]

Operating expense is the money invested in the organisation to transform inventory investments into throughput. This expense includes costs such as direct and indirect labour, resources, depreciation expense, administrative cost, external contractors, interest payments, maintenance and all other overhead that enable normal business operations. These costs ensure that a given level of capacity can be maintained. [79]

4.3.2 Performance measures

The values calculated for throughput, investment, and operating expense can be used to calculate three derived measures that are also used to monitor improvement efforts and support management decisions. These measures are net profit, return on investment, and productivity. Although these are also used in traditional accounting, they are calculated and interpreted slightly different in a throughput environment. [74]

Throughput Accounting (Performance Measures)		
Net Profit	=	Throughput – Operating Expense
Return on Investment	=	$\frac{\text{Net Profit}}{\text{Capital and/or Inventory}}$
Productivity	=	$\frac{\text{Throughput}}{\text{Operating Expense}}$

Figure 4.14: Throughput accounting: Performance measures

Net profit is throughput generated less operating expense, for a specified period of time. Traditional cost accounting aims to improve net profit by cost reduction, from a finite pool of operating expense, which limits the potential amount of profit growth and this can also leads to capacity cutbacks. However, throughput accounting focuses on actions to increase throughput, which has theoretical potential for infinite growth. [80]

Return on investment provides information about investments and their overall effect on throughput. These can be expressed in terms of capital or inventory. Capital ROI is uncommon because of the assumption that the system already has an excess level of capacity, with the exception of the constraint. Therefore, inventory ROI is more often used to support decisions, such as investment for constraint elevation.

ROI is calculated as net profit over investment. As mentioned before, the calculation is most often done with inventory investment instead of capital investment, because the focus must be on reduction of variable resources, not fixed assets. However, it is crucial to avoid resource reductions that have a negative impact on throughput. [79]

Productivity is a measure of how efficient the process is through the comparison of value added cost with operating expense; it is calculated as generated throughput over operating expense, for a specified period of time. This is used to determine how changes in operating expense may impact overall throughput. Productivity can also be shared with employees, because it does not disclose sensitive information, to act as a motivational driver that displays the operational performance of the system. [52]

4.3.3 Throughput accounting reconciliation

Throughput accounting can be reconciled with GAAP so that they can both co-exist without the need to maintain two sets of books. The reconciliation procedure provides the benefit of an internal format for standardised reports that complies with internal measurement information that is used to make strategic and operational decisions.

The differences between throughput accounting and GAAP must first be understood for successful reconciliation of these approaches. Although both approaches use the same measures they are calculated in a different manner and presented in a different format. The important difference is the distinct allocation of overhead and labour. [74]

Overhead are assigned to inventory when GAAP is preferred, and it is expensed as cost of sales in the period that the inventory is sold. However, throughput accounting states that overhead represents the cost of process capacity within a certain period of time, and therefore expenses the total system overhead in that specified period.

Direct labour is considered to be a traditional variable expense because of its direct relation to production volumes. Its cost is therefore assigned to inventory if GAAP is preferred. However, throughput accounting expenses directs labour in the current period, unless it is based on piece rate or commission. Direct labour cost is therefore defined to be in line with the type of remuneration and the production environment.

The allocation of overhead and direct labour to inventory with GAAP means that it can be stored as an asset across multiple accounting periods until it is charged as cost of sales when the inventory is sold. This provides a flawed performance reward system that encourages overproduction to shift some of these expenses from the current period's income statement and store it on the balance sheet as inventory. [79]

Throughput accounting follows a simple approach and only assigns material that was consumed within production to inventory because it is recognised as the only variable cost involved. Furthermore, it avoids performance reward systems that encourage overproduction. This is important because excess inventory is considered a liability.

The reconciliation approach consists of two steps to convert GAAP to throughput accounting. The first step is the adjustment of inventory levels, and the second step is the adjustment of the format. These reconciliation steps are discussed below. [74]

Step 1: Make adjustments to changes in inventory levels. The net income figure of these accounting approaches will be different when inventory levels changes within the specified period used for reports. This is because operating expenses in GAAP are either stored in or released from the inventory value listed on the balance sheet; however, throughput accounting records operating expenses in the current period.

If there is no volume change between the beginning and ending inventories, and the corresponding overhead and direct labour rates are identical, then both approaches will result in the same net value. This is because there is no reassignment of costs if the organisation sells everything that was produced within the reported financial period.

Table 4.3: Throughput accounting inventory adjustment

Inventory Adjustment			
Beginning Inventory Units		11 400	
Overhead Rate	R	5.50	
Labour Rate	R	4.30	
Beginning Inventory	**R**	**111 720**	(Overhead + Labour) x Inventory Units
Ending Inventory Units		22 400	
Overhead Rate	R	5.10	
Labour Rate	R	3.85	
Ending Inventory	**R**	**200 480**	(Overhead + Labour) x Inventory Units
Change in Inventory	**R**	**88 760**	Ending Overhead – Beginning Overhead

Table 4.3 shows how to calculate and adjust the changes in inventory levels. This procedure identifies the net change in inventory to remove overhead and labour that is stored as assets. Note that the respective rates are calculated as overhead and direct labour costs divided by the total amount of units produced. Table 4.3 also shows that higher production levels (inventory) can lead to lower overhead and labour rates.

Step 2: Make adjustments to the format. The layout of a GAAP statement specifies that overhead and direct labour is recorded together with direct material as cost of goods sold, which is then used to calculate the gross margin. Throughput accounting calculates throughput contribution instead of a gross margin because it assumes that the material consumed in production is the only variable expense and should be the sole contributor to cost of goods sold. The contribution to sales is therefore higher.

Furthermore, a GAAP income statement shows a breakdown of operating expenses with various expense categories such as wages, supplies, and utilities. Throughput accounting groups these expenses, including overhead and direct labour, into one category. This category can then be expanded into various levels if a more detailed overview of the expenditures is needed for further analysis of the income statement.

The example in Table 4.4 shows how to implement these two reconciliation steps as explained above. The inventory adjustment value is copied from Table 4.3, and the other values are fabricated for explanatory purposes. The purpose is to show that it is possible for GAAP to abuse overproduction (excess inventory) to cover a throughput loss because some of the current operating expenses are recorded as inventory. [79]

Table 4.4: Throughput accounting format adjustment

Format Adjustment	Cost Accounting	Step 1: Format	Step 2: Inventory	Throughput Accounting
Revenue	**R 1 725 000**			**R 1 725 000**
Cost of goods sold:				R -
Material	R 485 00			R 485 000
Direct Labour	R 295 000	R -295 000		R -
Overhead	R 320 000	R -320 000		R -
Total cost of goods	**R 1 100 000**			R **485 000**
Gross margin	**R 625 000**			
Throughput contribution				**R 1 240 000**
% to Sales	36%			72%
Operating expenses	**R 540 000**	R 615 000	R 88 760	**R 1 243 760**
Net profit	**R 85 000**			**R -3 760**

Also look at the difference between gross margin and throughput contribution. The reason is that throughput accounting considers the system as a whole, while GAAP allocates costs to specific products. Throughput accounting almost ignores gross margin analysis at product level, and is therefore a popular approach for the evaluation and prioritisation of improvement activities that can affect the entire organisation. [74]

5. Six Sigma Thinking

Six sigma is a quality orientated continuous improvement methodology that strives to reduce variation and improve process performance. It follows a team based problem solving approach to guide process improvement activities through the identification and elimination of root problems. This methodology is supported by various basic process improvement techniques as well as rigorous statistical tools, which require a skilled workforce that is arranged in a strict hierarchical management structure. [81]

History of six sigma

Quality as a concept continues to evolve. In the past, quality was simply defined as conformance to valid customer requirements. This is known as the goalpost view of quality and states that output is considered good as long as it falls within acceptable limits, called specification limits, around a desired value, called the nominal value or target value. But the definition of quality changed as the concept was further refined.

Another, more recent definition known as the Taguchi loss function view of quality states that quality is a predictable degree of uniformity and dependability, at low cost and suited to the market. This definition also states that losses accrue as soon as a quality characteristic of a product or service deviates from the nominal value. The Taguchi loss function, called the loss curve, expresses these deviation losses in a measurable format for analysis. Further development of this quality concept, together with Deming's theory of management, established the foundation for six sigma. [82]

Six sigma was conceptualised by Bill Smith, an engineer at Motorola, in 1986 as an organisational wide improvement strategy. It was further popularised when General Electric adopted it in 1995 with great success under the leadership of their former CEO, Jack Welsh. Both these companies played a major role in the development of six sigma from a metric to a methodology, and finally to a management system. [12]

The six sigma metric is designed to measure process variation and create processes that strive to produce no more than 3.4 defects per million opportunities. This quantity is calculated from a 6-sigma process, based on the assumption that the mean value from a stable and normal distribution of output can shift by as much as 1.5 standard deviations over time. The correctness of this assumption is often questioned by some statisticians, but it is generally accepted in the industry as a reliable quality measure.

The six sigma methodology builds on the six sigma metric. It is designed to make statistical process control a real-time operational application that allows for proactive improvement efforts. The introduction of the rigorous project-oriented DMAIC (Define, Measure, Analyse, Improve, and Control) cycle also makes six sigma a powerful team based problem solving and improvement methodology. This model provides a systematic analysis approach that aims to improve and control process performance.

The six sigma management system is more than just a methodology that focuses on data analysis to understand and minimise process variation with a set of optimisation and statistical improvement tools. It is also a practical system with a detailed focus on the identification and appreciation of customer requirements that align key processes to achieve of those requirements. Furthermore, the management system is required to drive rapid and sustainable continuous improvement throughout the organisation.

Focus of this chapter

The execution of six sigma relies on a technical approach that is governed by a management system. The bulk of this chapter focuses on this technical approach in terms of the DMAIC cycle. This chapter is then completed with a discussion on the system of profound knowledge, which is a management theory. However, the rigid hierarchical management structure is not discussed because it is not applicable in context of this project, which only focuses on improvements in small organisations.

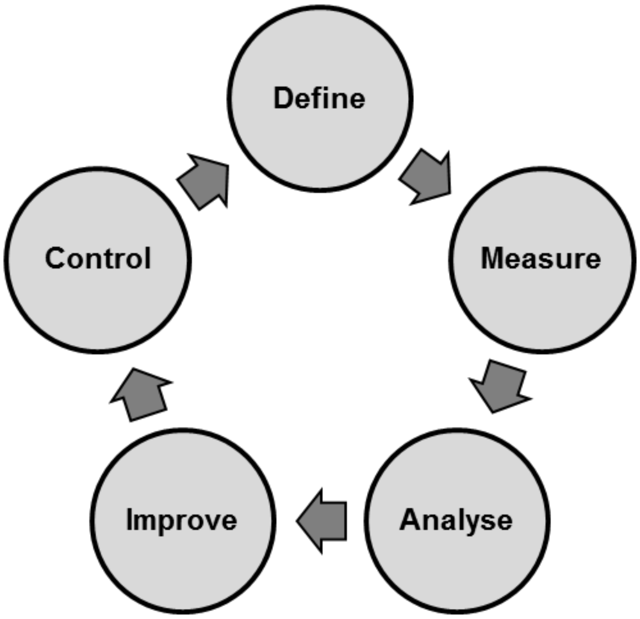


Figure 5.1: The six sigma DMAIC cycle

The DMAIC cycle provides the main structure for the technical approach; this project orientated problem solving approach is designed to improve current processes, and is supported by the application of several process tools. These tools can be divided into two main groups: statistical analysis tools and process optimisation tools. Both these tool sets are important for the successful execution of six sigma activities. [12]

Statistical analysis tools drive most of the analytical activities with data collected from process output, simulation, or experiment. These tools include basic statistics as well as advanced tools. The objectives of this report make it clear that it does not make sense to discuss some of the advanced statistical tools such as analysis of variance (ANOVA), regression, and design of experiments (DOE). The focus is therefore on basic statistics that are sufficient for successful implementation of analytical activities.

Process optimisation tools are the core drivers for process optimisation, design, and definition of operations. These tools are the main focus of this chapter because of their relative ease of implementation, which provide a foundation for analysis and improvement activities. They also promote process thinking and team based problem solving to identify key problems. These tools are discussed together with some basic statistical tools in context of the DMAIC cycle for successful improvement execution.

The final section of this chapter discusses the management theory, which focuses on the management of people through leadership, education and empowerment. This system strives to develop a culture of sustainable improvement. The emphasis on a strong management system with basic tools may be an unconventional approach toward six sigma, but this is crucial to ensure that the methodology, in the hands of the novice, is an exercise in problem solving, instead of an exercise in statistics. [15]

5.1 Define

The purpose of the define phase is to direct efforts toward a sensible improvement opportunity. This includes the rationale for improvement, an improvement plan, full comprehension of the relationships within the process, and an analysis to determine the customer requirements that are important to the process. These are discussed in terms of three main deliverables that comprise the define phase: (1) project charter, (2) SIPOC analysis, and (3) a voice of the customer to critical to quality analysis. [83]

5.1.1 Project charter

The project charter is considered by many as the most important document because it provides the rationale and structure for improvement activities. It also establishes clear expectations for the project to improve communication amongst the team. The team should therefore always refer to the charter to monitor progress and revise it to accommodate new information. Project charters should consist of a business case, problem statement, goal and objectives, scope, project plan, and team selection. [84]

Table 5.1: Project charter sections

Charter Section	Comments
Business Case	• Describe the purpose of the project • Describe potential benefits
Problem Statement	• Discuss the process problems • Express the quantitative impact
Goal and Objectives	• Set SMART targets • Use targets to evaluate progress
Project Scope	• Describe the project boundaries • Define the level of authority • Define the level of access to resources • Specify what is not within scope
Project Plan	• Provide milestones for guidance • Assign people responsible for each milestone • Use Gantt chart with DMAIC structure
Team Selection	• Select people with the necessary expertise • Assign detailed job responsibilities • Keep the team flexible

The *business case* is the strategic driver behind the project rationale. It describes the primary purpose and potential benefits for project initiation. These include the impact on the customer, process, and employees. A well-defined business case is important because it also serves as motivation to gain support from the affected stakeholders.

The *problem statement* discusses the fundamental problems that the business case is based on. This is often expressed in financial terms to emphasise the importance of the project. When numbers are not available the problem can also be expressed in terms of process performance or customer satisfaction. This statement must also be updated on a continuous basis as more data about the quantitative impact is collected.

The *goal and objectives* statement must contain specific measures with target values to drive improvement efforts. These must describe a successful project outcome so that the team can evaluate the progress of improvement activities and know when the goal has been accomplished. A general guideline for an effective goal statement is to set targets that are specific, measurable, achievable, relevant, and time bound.

The *scope* describes the boundaries of the project and specifies the start and end steps of the process under consideration. This ensures that the boundaries of the project do not change so that the focus of the improvement team is maintained on the right priorities. The scope must also define the level of authority that allows the team to make decision as well as their level of access to resources. The final part, which people often omit, is to determine what components are not within the scope.

The *project plan* is an operational document that provides the team with intermediate milestones to complete. These milestones guide the team through the project steps and enable them to track their progress. This can contain a Gantt chart to visualise each milestone with the people responsible for their completion. The phases of the DMAIC model are often used to provide a structure for more detailed milestones. [14]

Tasks	**Coordinator**	**Week**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Define															
Task 1	Matt														
Measure															
Task 2	Paul														
Task 3	Paul														
Analyse															
Task 4	John														
Task 5	Matt														
Improve															
Task 6	Frank														
Task 7	John														
Control															
Task 8	Matt														

Figure 5.2: Gantt chart

The last section, *team selection*, assigns detailed responsibilities to team members. It is important to determine the skill requirements of the project to select team members with the necessary expertise to fulfil those requirements. This ensures an efficient and effective team with the right people doing the right things. The team must also be flexible because the composition can change as the project charter is further refined.

5.1.2 SIPOC

The SIPOC (Suppliers, Inputs, Process, Outputs, and Customers) analysis is a high level process map that represents the essential elements of the studied process. This provides a basic process description, which allows team members to quickly develop a mutual appreciation of the process before improvement activities are initiated. [85]

The team can start the analysis at the end, with the customer, and work towards the suppliers. A team based approach is recommended to encourage rapid development and a more accurate analysis of the studied process. At this moment the start and end points of the process must be described as part of the scope in the project charter.

Process Name:				
Supplier	**Input**	**Process**	**Output**	**Customer**
Who are the suppliers?	*What do they supply?*	*High level process steps*	*What is provided by the process?*	*Who are the customers?*
1. 2. 3.				

Figure 5.3: SIPOC analysis

The *customers* are target entities that the process intends to satisfy. These include internal and external people, companies, systems, or downstream operations that receive output from any point in the process. The improvement team should focus on the satisfaction of customers that bring in the most value for the system as a whole.

The *outputs* are the products or services produced by the process and required by the customers. These can include outputs and requirements in terms of time, cost, quality, and safety. It is recommended to limit the list to three or four main outputs to keep the analysis simple, despite the fact the process may produce a larger variety.

The *process* is a high level map of operations and procedures that are required to transform the inputs into outputs. Decompose the process into four to seven of the most important steps between clear start and end points as specified in the project charter scope. This ensures that the team does not get caught up in too much detail.

The *inputs* are the resources required for an effective process. These include human resources, information, capital, equipment and other resources that are consumed or transformed in the process. It is suggested to limit the list to three or four main inputs.

The *suppliers* provide the inputs identified in the previous step. Suppliers include internal and external people, companies, systems, upstream processes, and other sources that are responsible for process inputs. The improvement team should focus on the satisfaction of suppliers that bring in the most value for the system as a whole.

The completed SIPOC analysis is the foundation for high level process definition and identification of process measures. This can also be used for the selection of a focus area for improvement activities. However, because this is only a high level analysis a more detailed map is probably required to find significant improvement opportunities.

5.1.3 VOC to CTQ analysis

The VOC (voice of the customer) to CTQ (critical to quality) analysis is an important technique to define a process, and is used to develop an appreciation of significant quality characteristics, which supports the identification and selection of improvement opportunities. This three step technique includes evaluation of customer perceived quality requirements, identification of primary requirements with the Kano model, and the translation of the requirements into process attributes that are critical to quality.

Step 1: Voice of the customer

The purpose of a VOC analysis is to identify the main drivers of customer satisfaction and ensure that the studied process is aligned with these drivers. This analysis uses feedback from the customers identified in the SIPOC analysis to determine drivers in terms of cost, time, quality, safety, and other requirements that they may have. The problem is that customers express their requirements in a colloquial and imprecise manner, so it is important to use a structured approach to analyse their feedback. [12]

Information for the VOC analysis is collected from two types of sources: reactive and proactive. Reactive sources are information that is already available and just require some evaluation. These include customer complaints, sales information, technical support, warranty claims, and returns. On the other hand, proactive sources provide additional information from interviews, surveys, market research, and observations.

Process Name:			
VOC	**Customer**	**Information Source**	**Driver**
What did the customers say?	*Who are the customers?*	*How was the information collected*	*What are the drivers critical to?*
1. 2. 3.			

Figure 5.4: VOC analysis

Once the VOC analysis is completed the data needs to be analysed. The next step discusses how to utilise the Kano model for identification of the significant customer requirements. These must then be transformed into critical to quality characteristics.

Step 2: Kano model

The Kano model, developed by Noriaki Kano, is used to analyse and organise the VOC data, which was collected in the previous step, to estimate their effect on the different levels of customer requirements and satisfaction. Kano suggested that the levels of customer requirements are specifications, expectations, and delighters. [86]

Specifications include technical requirements and information that are requested explicitly by the customer. This information provides a direct reflection of what the customer perceives as core performance of the product or service. Specification requirements are therefore proportional to customer satisfaction. This means that higher fulfilment of the specification will result in higher satisfaction of the customer.

Expectations are basic requirements that are fundamental to customer satisfaction even though customers do not explicitly mention this information. This is because expectation requirements are considered obvious and inherent to performance requests. The fulfilment of expectations will therefore not result in added satisfaction; however, unfulfilled expectations will lead to a high level of customer dissatisfaction.

Delighters are unspecified characteristics that differentiate between performance to give a product or service a potential competitive advantage. Their absence cannot cause customer dissatisfaction because customers don't anticipate them. But their presence cause satisfaction to increase faster than the rate of expectation fulfilment.

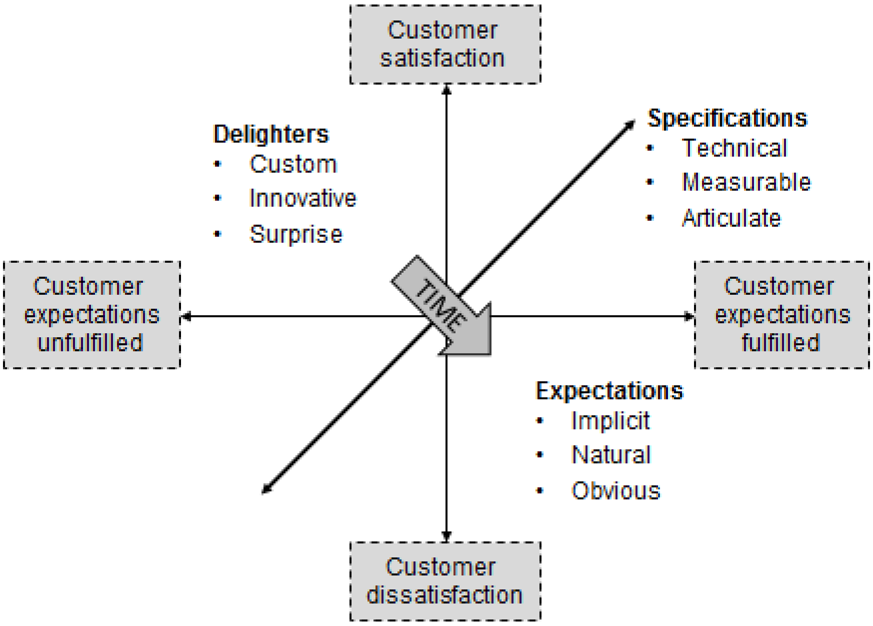


Figure 5.5: Kano model

The improvement team must understand these categories and organise the VOC data on the Kano model to determine the critical customer requirements. These are the requirements that fulfil expectations, meet specifications, and provide potential delighters. The model should also be evaluated regularly because classification of customer requirements in the three groups changes over time (Kano effect). This is because customers get accustomed to innovative performance characteristics. [87]

Step 3: Critical to quality

Critical to quality (CTQ) characteristic identification is vital for effective improvement opportunity selection. These characteristics are derived from the critical customer requirements that were identified in the Kano model. The role of each characteristic in the process must be understood to ensure that the focus is on the right things. [12]

The key issue addressed by the customers must be isolated and clarified because customers often express their requirements in colloquial language. However, the key issues are often defined at too high a level to be directly useful for improvement. It is therefore important to transform these key issues into applicable CTQ characteristics.

CTQ characteristics are defined as requirements from a customer perspective, which are transformed to characteristics from a process perspective. This transformation approach requires operational definitions with target values for each characteristic to drive the desired behaviour of the affected people and to track improvement progress.

Process Name:			
Continue from VOC analysis …	**Key Issue**	**CTQ Characteristic**	**Target value**
	What are the key issues?	*What are the requirements, in a measurable form?*	*What are the target values in standard units?*

Figure 5.6: CTQ analysis

The VOC to CTQ analysis is completed once the CTQ characteristics are identified and defined. The team can use these characteristics to select focused improvement opportunities that will have a significant and positive impact on customer satisfaction.

5.2 Measure

The purpose of the measure phase is to collect and validate measures that represent the improvement area. This includes a data collection plan, selection of measures, validation of the measurement system, and the establishment of a baseline. Data collection is discussed in the PDCA cycle; therefore, only three of these deliverables are discussed in this section for successful completion of this phase: (1) cause and effect matrix, (2) measurement system analysis, and (3) performance baseline. [83]

5.2.1 Cause and effect matrix

The cause and effect matrix uses the CTQ characteristics, which was identified in the previous step, to determine the key input measures that influence the process. This information is crucial to ensure that the team focus on the significant improvement opportunities that affect the process as a whole. Once these are identified the team can establish a performance baseline to track and control improvement activities. [12]

The cause and effect matrix is often required when the process has multiple CTQ characteristics. All the significant input characteristics can then be identified though their correlation with weighted CTQ characteristics. This process is discusses below.

Step 1: List the CTQ characteristics at the top of the matrix. Use a scale from 1 to 10 to assign a weight for each characteristic in terms of their relative importance to the final customer. Let 1 indicates the least critical and 10 the most critical characteristics.

Process Name: Bread production line				
	CTQ characteristics			
	Cycle Time	Cost	Sigma Level	
Weight ⇨	8	10	6	
Input characteristics ⇩	Correlation of input to CTQ characteristics			**Total**
Vendor	3	3	1	**60**
Flour Grade	0	9	9	**144**
Oven Temperature	9	3	9	**156**
SCALE: 0 = None 1 = Weak 3 = Moderate 9 Strong				

Figure 5.7: Cause and effect matrix

Step 2: List in the first column all input characteristics that may affect any of the CTQ characteristics. Rate the degree to which the input characteristics are correlated to each CTQ characteristic. Use a scale where 0 indicates no correlation, 3 indicates weak correlation, 6 indicates moderate correlation, and 9 indicates strong correlation.

Step 3: Multiply each correlation value with the weight and sum across each row to determine the relative importance of each input characteristic. The inputs with the highest total scores must be measured together with the CTQ characteristics. These significant inputs and CTQ characteristics are the critical process characteristics.

5.2.2 Measurement system analysis

Measurement system analysis (MSA) is crucial to ensure that data driven decisions are based on valid data, even though this is often neglected by inexperienced six sigma practitioners because they do not realise that the measurement system is also subjected to variation as any other process; MSA also requires statistical knowledge that can discourage novice practitioners. However, it is important to understand the philosophy behind MSA because of its relevance to various project applications. [88]

The measurement system is a process with specific inputs that are transformed to produce an output in the form of a measurement. It is therefore normal to assume that the measurement system can produce some variation that influences the validity of measurements. The source of this variation can be traced back to various system factors; these can include stability, bias, linearity, discrimination, and precision. [89]

Stability is the capability of a measure to maintain a constant distribution over time with a given measurement approach. Measurement data can be plotted on a time based chart to visually represent any deviation. The difference between the mean values of the measurement series are used to calculate the stability. Deviation can result from various environmental effects and changes in the measurement system.

Bias is the difference between the average of the measurement data and the actual reference value. The reference value is an industry based standard that provides an undisputed target for a specific measure. Several measurements must be made to make a valid conclusion about the bias. The objective is to reach the reference value.

Linearity describes how reliable the measurement approach is over a diverse range of measurement types. A particular approach may not be suitable for measures with different characteristics because tool calibration is based on the assumption that the same conditions prevail. The change in deviation from the mean values calculated from the actual measures of the measurement range is used to determine linearity.

Discrimination is the capability of the measurement system to adapt to small changes in a measurement characteristic. The problem is that even these small changes can affect the credibility of the measurement system. Therefore, if the system is not able to adapt appropriately to these changes, errors in the process will be difficult to find.

Precision is crucial to MSA because of its high contribution to the standard deviation of the measurement system. It is therefore common to assign considerable statistical effort to determine its significance in terms of system repeatability and reproducibility.

Repeatability variation is a result of the gauge itself. The problem occurs when an operator measures a characteristic multiple times with the same gauge and obtains different results in fixed conditions. This variation can be reduced or eliminated with gauge modifications; otherwise a new gauge must be used for future measurements.

Reproducibility variation is a result of differences between operators and inconsistent measurement procedures. The problem occurs when multiple operators measure a characteristic multiple times with the same gauge and obtain different results. One solution is to train operators to use operational definitions and standardised methods.

Repeatability and reproducibility studies are most reliable when conducted as blind studies where a sample of representative characteristics is measured two or three times by two or three independent operators; then analyse the data to validate the consistency and accuracy of the measured outcomes. Computer software is often used to deal with this complicated statistical analysis and quantify the variation. [12]

5.2.3 Performance baseline

The final deliverable for the measure phase is to create a performance baseline for the critical process characteristics as soon as the measurement system is verified as consistent and accurate; a baseline represents the initial performance of a process characteristic and also serves as a reference point to track improvement efforts. [90]

There are several measures that can be used as a baseline for the critical process characteristics. These measures include defect rate, process yield, and capability indices. Capability indices use relatively complex measures based on the assumption of normality and is limited to stable processes. It is therefore not discussed in this report because it may lead to a great deal of confusion for novice practitioners. [15]

Measure 1: Process defect rate

A unit (product or service) that does not perform within specification is considered a defective. This means that it produced a nonconformance, known as a defect, on one of its fundamental characteristics; each of these characteristics provides a defect opportunity. Defect rate is most often measured in terms of defects per unit (DPU), defects per opportunity (DPO), and defects per million opportunities (DPMO). [12]

Defects per unit:

$$= \frac{\text{Total number of defects}}{\text{Number of units}}$$

Defects per opportunity:

$$= \frac{\text{Total number of defects}}{\text{Total number of defect opportunities}}$$

Defects per million opportunities:

= Defects per opportunity x 1 000 000

Sigma Level	**DPMO** *(shift = 1.5)*
6.0	3.40
5.0	233
4.0	6 210
3.0	66 807
2.0	308 538
1.0	691 462

Figure 5.8: Process defect rate measures

DPU refers to the average number of defects per unit. However, this value does not provide a fair comparison between units with different levels of complexity because the opportunity for defects is larger in complex units. It is therefore recommended to determine the defects per opportunity to create a comparable performance baseline.

DPO refers to the total number of defects in proportion to the total number of defect opportunities. This allows the measure to consider the complexity of a unit. However, the value of DPO can become very small when calculations are done on complex units with thousands of defect opportunities. Therefore, rather multiply this value with one million and use DPMO as the baseline. Notice that DPMO is also the benchmark rate that is used to describe the sigma level of a process as shown in Figure 5.8. [15]

Measure 2: Process yield

The complementary measure of defect rate is process yield, which is defined as the proportion of units that perform within specification. Measures derived from yield are also appropriate to describe process capability. Three types of yield can be used to create a baseline: (1) final yield, (2) first pass yield, and (3) rolled throughput yield. [91]

Final yield is the ratio of the total number of defect free units that a process delivers over the number of units that entered the system. The problem is that this traditional method to calculate yield does not consider the resources used for rework, which cause hidden factories to originate. A hidden factory is an extension of the process that is caused when the process does not run within specification limits the first time.

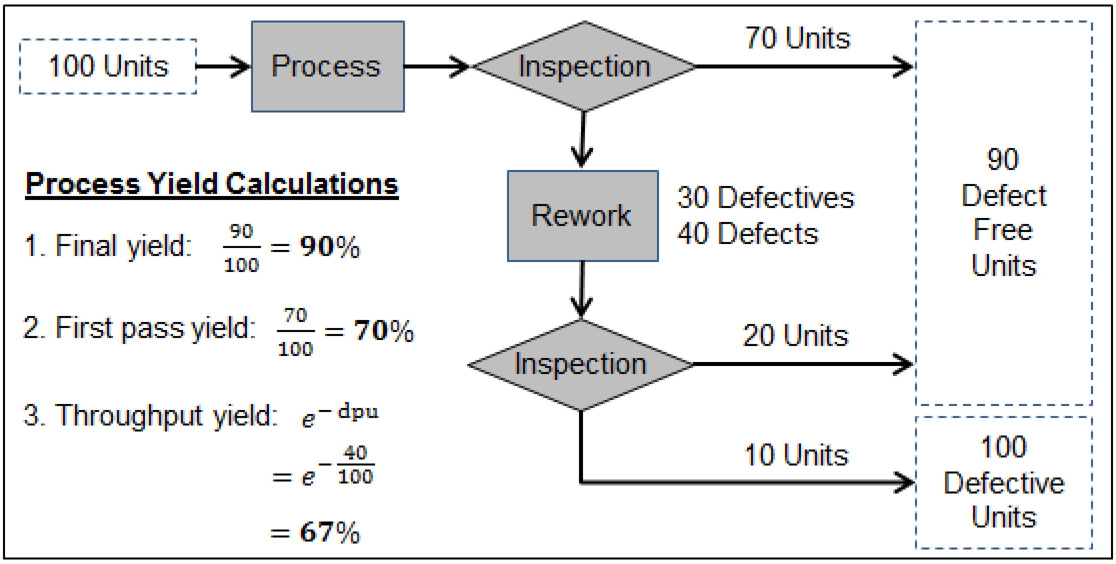


Figure 5.9: Process yield measures

First pass yield (FPY) is a unit based measure that indicates the percentage of defect free units that passed through a process the first time without rework. The problem with FPY is its complete dependence on the distribution of defects. For example, suppose 100 units enter a process and 10 defects are produced. Now consider a scenario where all 10 defects occurred in one unit and another scenario where the 10 defects occurred in 10 different units, which give a respective FPY of 99% and 90%.

Throughput yield is a defect based measure that differs from FPY in two fundamental criteria. First, it refers to the number of defects produced, rather than the number of defective units. Second, it is used to predict future yield based on the assumption that defects are produced according to a Poisson distribution. These criteria ensure that throughput yield gives the same value regardless of where the defects occurred; so it is a more consistent measure, than unit based yield, of the process as a whole.

5.3 Analyse

The purpose of the analyse phase is to convert the raw data collected in the previous phase into information that provides insight into the process. This includes the use of graphical tools to interpret and communicate the data. Some analysis tools such as cause and effect diagrams, histograms, and run charts are discussed in the PDCA cycle. Only Pareto analysis and scatter plots are therefore discussed in this section to respectively identify root causes and evaluate correlation between measures. [12]

5.3.1 Pareto analysis

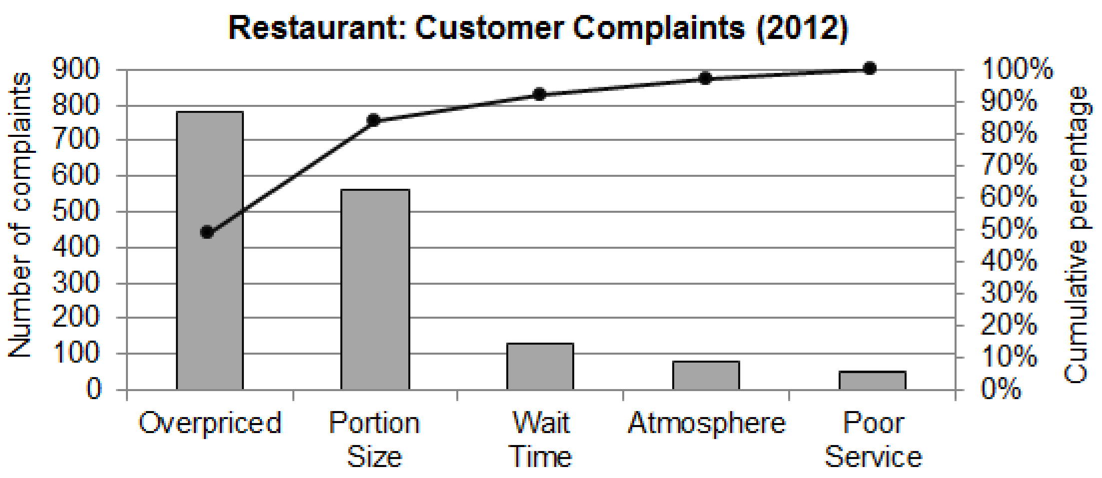
Pareto analysis, developed by Vilfredo Pareto, is an analytical tool that is used for identification and prioritisation of events. This is based on the assumption that 20 percent of events have 80 of the impact. The 20 percent is known as the vital few and the remainder as the trivial many. The vital few represent the most important events and should therefore be the main focus of future improvement activities. [92]

The analysis includes the construction of a column chart that is used to organise data in descending order of importance. Each column signifies the occurrence frequency of an event from a variety of qualitative categories such as type of defect, customer needs, skills required, and investment opportunities. This diverse range of application makes it more than just a problem solving tool, but also a respectable prioritisation tool. The next five steps provide a basic approach to construct a Pareto diagram. [15]

Step 1: Identify the possible opportunities (or problems) for a particular process with the help of idea generation techniques. Collect data for each event in accordance to specified operational definitions and decide whether cost or number of occurrence is more important. The order of priority can be different between a cost and a frequency chart when there is a high variation in cost of events. Also remember that the cost Pareto chart does not consider invisible cost such as the cost of an unhappy customer.

Step 2: Construct a frequency table for the event count. Multiply each value with the cost related to each event if the cost approach is preferred. Several small data sets that accumulated to less than 50 percent of the total can be grouped together into an “other” category. Sort the opportunities in descending order of importance, and then add a column that shows the cumulative percentage of each value from top to bottom.

Step 3: Prepare the chart. Label the left axis with equal intervals from 0 to a number equal to or larger than the total cost or counts. Provide a short caption to describe the unit of measurement. Label the horizontal axis with the event categories from largest to smallest. Then label the right axis from 0 to 100% and line up the 100% with the total on the left axis to synchronise the cumulative percentage with the total cost or total count. Chart preparation is then completed with the addition of a title and a date.



Customer complaints	Count	Cumulative count	Cumulative %
Overpriced	780	780	49%
Portion Size	560	1340	**84%**
Wait Time	130	130	92%
Atmosphere	80	1550	97%
Poor Service	50	1600	100%

Figure 5.10: Pareto analysis

Step 4: Use columns to plot the data in descending order from left to right. The height of each column must be equal to the total cost or count of the specific category. Plot a cumulative percentage line from the centre of the first column where the count corresponds with the cumulative count axis on the right and continue to the centre of the second column so that it also corresponds with the cumulative axis. Repeat until the line reaches the final column to indicate the cumulative frequency of 100 percent.

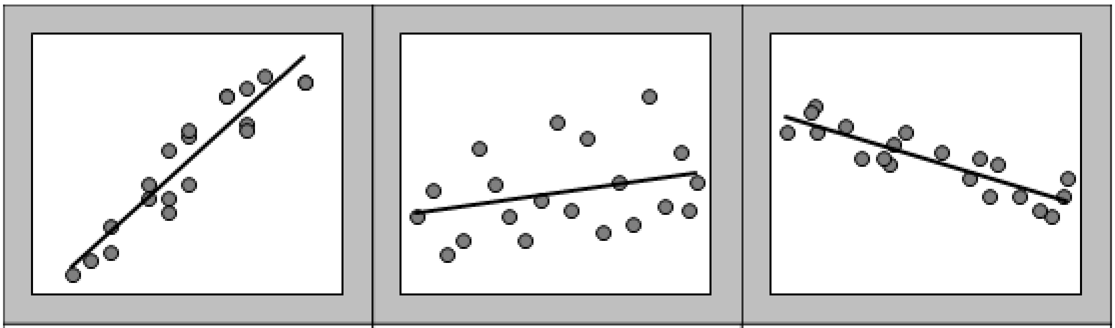
Step 5: Analyse the completed Pareto chart. Look for a sudden decline in the slope of the cumulative line. This represents the break point that separates the significant few from the trivial many. If the columns are almost the same height the cumulative line will be flat and the Pareto principle does not hold. When this happens it is crucial to categorise the events in a different manner to find other significant opportunities.

Once these steps are completed the improvement team can focus their efforts on the significant opportunities. Successful exploitation of these opportunities can lead to a change in their prioritisation. This enforces continuous improvement because all the exploited opportunities are replaced with the next most significant opportunities. The Pareto chart is also used to track efforts and see whether the expected results are achieved in terms of how opportunities are prioritised when the chart is revised. [12]

5.3.2 Scatter plot

A scatter plot is a graphical tool used to determine a possible relationship between two characteristics. The quantification of this relation is known as correlation. This information is important to understand the effect that the input characteristics can have on the outcome characteristics. Significant characteristics can be extracted from the cause and effect matrix. Note that these characteristics must be captured at the same time to provide unbiased data that is relevant for time based analyses. [93]

Once the input and output data is collected the scatter plot can be constructed. First label two axes with the two respective characteristics. Then pair the simultaneous measured values for the two characteristics together to form x-y points. Plot these points on the two axis plot. Although scatter plots is mostly used for two continuous characteristics, it can also be used when one of the characteristic are measured in discrete values. Figure 5.11 shows different types of continuous data correlation. [90]



Correlation		Correlation		Correlation	
Amount:	High	**Amount:**	Low	**Amount:**	High
Direction:	Positive	**Direction:**	Positive	**Direction:**	Negative
Strength:	Strong	**Strength:**	Weak	**Strength:**	Weak

Figure 5.11: Scatter plots and correlation interpretation

The figure above shows that the scatter plot is named after the scattered clusters of dots. These scatter plots can be interpreted at a glance to provide three important types of information about the correlation between two continuous characteristics: (1) amount of correlation, (2) direction of correlation, and (3) strength of correlation.

The *amount of correlation* can be determined by the position of points relative to the trend line. When two characteristics are unrelated (no correlation) then the plotted points are randomly scattered and there is no trend among them. In the case of high correlation, the points are tightly clustered around the trend line. A rule of thumb is to lay a fat pencil on top of the trend line; if the pencil covers up the plotted points, there is high enough correlation between the two characteristics to accept significance.

The *direction of correlation* determines if a characteristic either inhibits or enhance the outcome of another characteristic. Two characteristics are positively correlated if the relationship indicates that an increase in one characteristic causes an increase in the other. On the other hand, a negative correlation indicates that an increase in one characteristic translates into a decrease in the other, and the other way around.

The *strength of correlation* is the magnitude of the effect that one characteristic has on the other. A trend line is therefore added to the plot to visualise the magnitude of correlation by means of its slope; a steep slope indicates a strong correlation effect, while a gentle slope indicates a weak effect. Statistics can be used to get an exact value for correlation, but the trend line is often sufficient to determine significance.

5.4 Improve

The purpose of the improve phase is to generate and implement solutions that will eliminate problems and reduce variation. This requires that the entire team shift their mindset from analytical studies to creative thinking. Several idea generation and risk evaluation techniques can be used to get stakeholder support and follow through with implementation. One approach is pilot improvement, discussed in the PDCA cycle; but the six thinking hats and failure mode and effect analysis can also be used. [12]

5.4.1 Six thinking hats

Edward De Bono created six thinking hats in 1985 as a method to look at a problem from several different perspectives until the problems is solved. With this method he introduced the idea of lateral thinking; a thinking style that is not linear, sequential, or logical. It requires participant to look in the same direction at any moment.This helps to move away from habitual thinking styles and towards a rounded view of a process.

Lateral thinking includes constructive and creative thinking that also encourages the cooperation and coordination of teams. It deals with only one aspect at a time and is concerned with “what can be”. This approach is opposite to traditional thinking that is based on the philosophies of Socrates, Plato, and Aristotle. Traditional thinking deals with many aspects at a time and is concerned with “what is”, which is determined by analysis, judgment and argument, without team collaboration and cooperation. [94]

Six thinking hats can be used by either individuals or teams, where it can minimise the confrontations that happen when people with different perspectives discuss the same problem. The approach consists of only six imaginary hats that are used one at a time; each hat is a different colour and represents a different style of thinking. [12]

The *white* hat calls for information in terms of facts and numbers at hand. Information is presented in a neutral and objective way to determine what is available, what is needed, and how it can be obtained. This requires participants to set aside subjective beliefs, arguments, and opinions to avoid potential deceptive or incorrect information.

The *green* hat represents an environment that encourages divergent thinking so that creative possibilities and alternative ideas can be explored. Various lateral thinking techniques can be used to support divergent thinking and identify opportunities. This involves participants to set aside their habits of recognition, judgment, and criticism.

The *yellow* hat signifies optimism and a positive attitude to support the deliberate search for logical benefits and feasible implementation of a proposed idea. Benefits are not always obvious and it might be necessary to search for some advantageous opportunities; so every creative green hat idea deserves some yellow hat attention.

The *black* hat calls for caution and critical judgment to identify obstacles and avoid unrealistic solutions. This is vital because mistakes can be disastrous if suggestions do not fit the facts; but do not overuse cautious thinking because too much negative thoughts can destroy creative ideas, especially in the early stages of problem solving.

The *red* hat signifies intuition, hunches and emotions. It provides individuals with the opportunity to state their perspectives without explanation or justification. This helps teams to reveal conflict and emotions openly without fear of retribution; it is always valuable to share true emotions because emotions based on logic can be spurious.

The *blue* hat controls and organises the thinking process. This provides feedback for the team and guides them through the entire thinking process. Therefore, start with the blue hat to define the current situation or issue, set the agenda for thinking, and determine the sequence or utilisation of other hats; also, end with it to summarise what have been achieved, what have been learned, and what should be done next.

White Hat *Facts; Data; Information* • What information do we have? • What information do we need? Set aside arguments and opinions.	**Green Hat** *Creativity; Possibilities; Growth* • What are possible solutions? • What are the alternatives? Set aside judgment and criticism.
Yellow Hat *Optimism; Positive; Benefits* • Why is this proposal preferable? • How can we make this work? Every idea deserves positive attention.	**Black Hat** *Judgment; Caution; Evaluation* • What are the obstacles? • What are the weaknesses? Overuse can stifle creative ideas.
Red Hat *Emotions; Intuition; Hunches* • How do I feel about this right now? • How will I react to this idea? States perspective without justification.	**Blue Hat** *Organise; Control; Decisions* • What do we want to achieve? • What have we achieved? Manage the thinking process.

Figure 5.12: Six thinking hats

These hats can be used by individuals or teams to reduce team conflict. The crucial factor is that participants wear the same colour hat at the same time, because each hat represents a specific attitude to adopt. This requires discipline from each person to stay focused. The sequence of the hats is not important and hats can be used on their own at any point as often as needed, or as a sequence of two or more hats. [95]

5.4.2 Failure mode and effect analysis

Failure mode and effect analysis (FMEA) is a systematic approach used to determine in what ways a technical system might fail, the causes of failure, and the impact that failures might have on customer satisfaction and process performance. This is crucial to reduce or eliminate failure risks associated with improvement implementation. [14]

FMEA is standardised for proactive process evaluation to eliminate potential failure causes before actual failure occurs. The prioritisation of failures is also an important part of FMEA. This approach ensures that stakeholders are more comfortable with the process because potential problems can be avoided to make the process more secure. The steps below guide FMEA for failure identification and prioritisation. [96]

Step 1: Review the process to be analysed and list the relevant components. This information can be extracted from a flowchart or a fishbone diagram. FMEA suggests that people from different functional areas contribute ideas, to ensure that a realistic view of the process is provided for further evaluation of all the individual components.

Step 2: Identify potential ways in which the components of the process might fail; these are known as the failure modes. The improvement team can brainstorm or use alternative idea generation techniques for the identification of potential failure modes.

Step 3: Describe and asses the *severity* of the probable effect, or impact, that each failure mode might have on customer satisfaction and process performance. A low severity failure is unlikely to have any noticeable impact on the customer or system, while a serious failure might lead to functional problems as well as safety concerns.

Step 4: Describe and asses the occurrence *probability* of the identified effects due to potential root causes of failure; various methods can be used to determine these root causes. A low probability indicates that failures are not likely to occur, while a high probability shows that the system needs revision and modification to be more stable.

Step 5: Describe and access the *detectability* of the current control system to identify a failure before it influences the customer; this is the ability of the system to prevent the failure itself or the impact in the event of a failure. A low detectability score means that a failure can be detected immediately or at least in the next process step, while a high detectability score indicates that it is difficult to recognise and eliminate a failure.

Step 6: Calculate the risk priority number (RPN) to prioritise the importance of each failure mode. The RPN is the product of *severity*, *probability*, and *detectability,* for each respective failure mode. Once these are calculated the team can focus on the most important failure modes; the higher the RPN, the higher the importance of the failure mode. The RPNs can then be plotted on a Pareto chart to visualise priorities.

Step 7: Prepare a plan to eliminate risks associated with high priority failures. Identify the characteristics that are necessary to prevent a particular failure mode and define them as critical. Then try to avoid the failure itself or mitigate the effects associated with the failure. Otherwise, determine a suitable response in case the failure occurs.

RPN is a primary indicator of failure seriousness, but it us it not the only important output of a FMEA. The relationship between the failure factors (severity, probability, and detectability) must be considered because a failure might not be critical by itself, but can have a serious effect when combined with other failures. Therefore, always consider combinations of potential failures and their causes, conditions, and effects.

Process Steps	Failure Modes	Failure Effects	Severity	Failure Causes	Probability	Failure Controls	Detectability	**Risk Priority Number**
…	…	…	*S*	…	*P*	…	*D*	*S x P x D*

Severity Scores		**Probability scores**		**Detectability Scores**	
1 – 2	Almost invisible	1 – 2	Unlikely	1 – 2	Obvious failure
3 – 4	Minor failure	3 – 4	Rarely	3 – 4	Easy
5 – 6	Moderate failure	5 – 6	Sometimes	5 – 6	Moderate
7 – 8	Major failure	7 – 8	Frequently	7 – 8	Difficult
9 – 10	Serious failure	9 – 10	Very often	9 – 10	Undetectable
Note that these scores are just guidelines and require operational definitions.					

Figure 5.13: Failure mode and effect analysis

5.5 Control

The purpose of the control phase is to monitor and regulate the process to sustain improvement efforts after the project is completed and the team is disbanded. This provides opportunities to ensure that new behaviours become routine, even though it might take some time, through the use of control charts to guarantee performance based on the amount of variation that the process exhibits. However, before control charts can be understood, it is necessary to expand on the concept of variation. [81]

Variation

Walter A. Shewart was one of the pioneers who developed the theory of variation back in the 1920s. He stated that everything we observe or measure varies because variation is inherent to all processes; but organisations are forced to make decision based on these values, which might influence performance. Variation is therefore an important concept that six sigma aims to understand, monitor, and control. Shewart categorised variation as common cause variation and special cause variation. [97]

Common cause variation is due to natural variation that is inherent to the process, or because of how the process is managed, or because of the internal environment. It is often considered beyond the control of the individual and employees should therefore not be held accountable for such process problems; management is responsible to isolate and reduce common causes of variation to achieve real quality improvements.

Special cause variation is due to assignable causes that is not a regular part of the process, but arise because of specific circumstances. This means that it is a result of factors outside the process and an exception to standard operation. People closest to the process are responsible for the detection, avoidance, and rectification of this type of variation when possible; this is important to continuous improvement. However, management must set policies to detect and control the special causes of variation.

Table 5.2: Causes of variation

Common cause variation	Special cause variation
• Process design • Improper material • Poor instructions • Inadequate lightning • Ambiguous policies	• Untrained employee • Power failure • Machine break down • New raw material • Safety accident

When a process does not exhibit special cause variation it is considered stable. This means the process is in statistical control, although common cause variation might still be present. A stable process is a basic requirement for process improvement efforts. The advantages include known process capability, efficient operations, predictable performance in the near future, and accurate improvement measures.

There are two fundamental types of mistakes people make in the pursuit of a stable process. The first mistake, called tampering, is to treat common cause variation as special cause variation and adjust the system; this is by far the more frequent of the two mistakes. The second mistake is to treat special cause variation as common cause variation and accept the problem. Differentiation between the types of variation is therefore important so that appropriate actions can be taken for improvement. [15]

The theory of variation is also important because it is good practice to always reduce and control variation even when the process is stable. Management must focus on continuous reduction of variation to ensure predictable process output. They should also include employees to sustain improvements with basic statistical tools and time based charts; the main statistical tool used for this purpose is the control chart. [12]

5.5.1 Control charts introduction

Shewhart introduced control charts in the 1920s, as an extension of the run chart, to distinguish between common cause variation and special cause variation. He stated that a process must be stable and kept in control to ensure efficient management and to enable predictable performance. Controls charts are nowadays accepted in many situations as the main tool of statistical process control, although it is often adequate to view patterns of data on run charts. However, the basic concept of control charts is discussed because it is required to better understand statistical process control. [98]

Control charts provide a graphical representation for process characteristics plotted against time to identify deviation from the mean, process shifts, or unusual event that occurred; this is important for effective continuous improvement. Therefore, control charts provide management with guidance to take action and avoid the two common mistakes made in the pursuit to create stable processes. It also permits management to strive towards the ideal process through the continuous reduction of variation. [15]

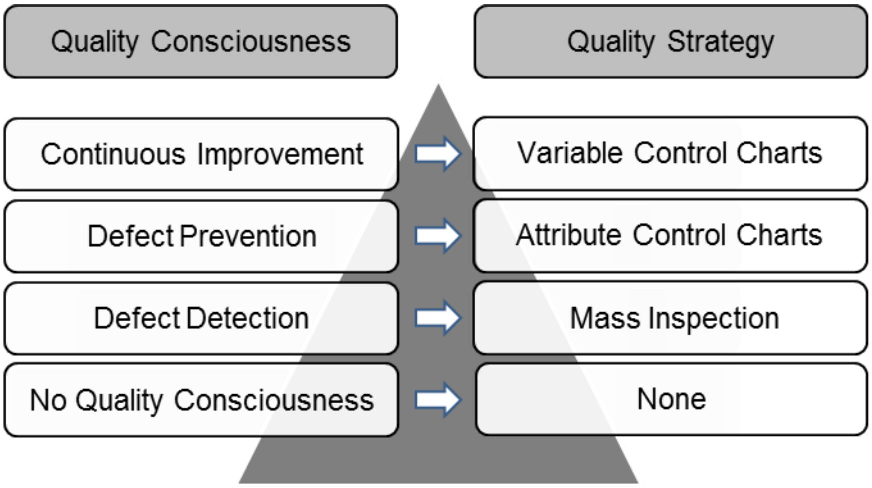


Figure 5.14: Quality consciousness versus quality strategy

Information and guidance provided by control charts can also be used for evaluation purposes. First, retrospective examination of a chart indicates whether the process has been in statistical control. Second, evaluation of the current situation supports tactical decisions to maintain a state of statistical control. Third, it predicts the near future state of a process based on statistical evidence and process knowledge. [15]

Different types of control charts are used for different scenarios. The appropriate type of control chart depends on the type of data available, or the quality consciousness of the organisation. Organisations that have progressed from defect detection, or mass inspection, to defect prevention should use attribute control charts. Only then can they advance to a state of continuous improvement and use variable control charts.

5.5.2 Attribute control charts

Attribute control charts use discrete data to promote the goalpost view of quality and create awareness of defect prevention. There two main types of attribute charts are classification charts and count charts. The chart type depends on the nature of the data; whether the data is the number or proportion of defects or defective units. [99]

Classification charts consist of **p charts** and **np charts**, which are respectively used to deal with proportion and number of defectives. Subgroup sizes for p charts may vary because it is expressed in proportions; however, subgroup sizes for np charts must remain constant. Therefore, np charts are often used to introduce control charts to people, because some people would rather work with whole numbers than fractions.

Count charts consist of **u charts** and **c charts,** which are respectively used to deal with proportion and number of defects (events) per area of opportunity; note that the area of opportunity can be a product, a time period, a geographical region, or other areas where one or more defects can be observed. Subgroup sizes for u charts may vary because it is expressed in proportions; however, subgroup sizes for c charts must be defined from constant areas of opportunity for reliable control analysis.

Attribute charts support the identification of special causes of variation, even though their usage is restricted to defects and defectives. This is a form of defect prevention, which may lead to improved processes that require the examination of excessive subgroup sizes to detect undesirable events. Therefore, inspection cost increases and the charts become inefficient as the fraction of defective output approaches zero.

Another disadvantage of attribute control charts is their limitation in the identification and isolation of individual special causes of variation, because multiple sources of variation may mask one another and give the impression that the process is stable, even when variation exists. Attribute controls charts are therefore only considered as a milestone towards true continuous improvement; so a more reliable and informative approach is required for further process improvement. This should lead to the next level of quality consciousness that encourages the use of variable control charts. [15]

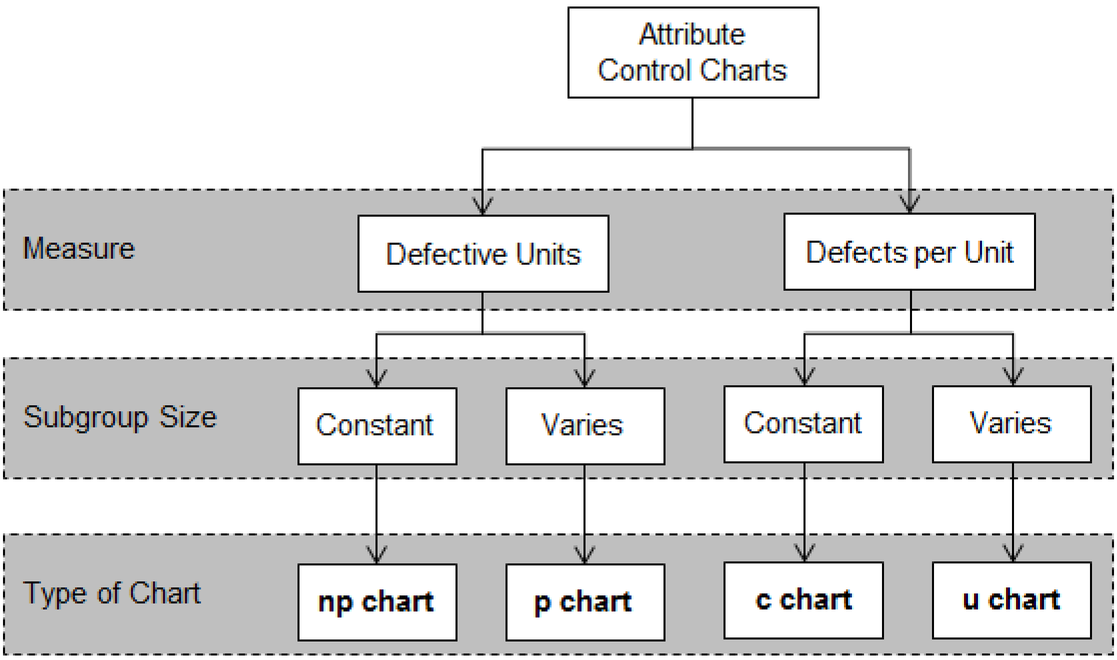


Figure 5.15: Attribute control chart selection

5.5.3 Variable control charts

Variable control charts use continuous data to promote the Taguchi loss function view of quality and create awareness of improvement. These types of charts reveal the information obtained though numerical measurements to enable the reduction of unit-to-unit variation. Variable charts are preferred over attribute charts because they do not mask valuable information that is crucial for continuous improvement, and to reduce the difference between customer requirements and process performance. [99]

Continuous data control requires two charts for complete process analysis because numerical measures provide more information than attribute data; one chart is used to monitor the location and one is used to monitor the variance of the data. These charts are grouped together into three sets of control charts: (1) x-bar and R charts, (2) x-bar and s charts, and (3) individual and moving range charts; the appropriate variable chart type is determined by the subgroup size that is used for data collection.

X-bar and R charts are used with subgroup sizes of two to nine. These charts are respective plots of the subgroup average, x-bar, to monitor process location, and the subgroup range, R, to monitor the process variance; "R" is a robust estimator of the standard deviation based on the average subgroup range. This simplified estimation approach makes x-bar and R charts the preferred choice for manual control analysis.

X-bar and s charts are used with subgroup sizes of 10 or more. These charts are respective plots of the subgroup average, x-bar, to monitor process location, and the standard error, s, to monitor the process variance; s is a more accurate, statistical estimator than R and also less robust because R is more sensitive to changes in the population shape. But contrast to the smaller standard error is the expensive cost of larger subgroup sizes and more complex calculations. However, computer software can be used for the construction of x-bar and s charts without tedious calculations.

Individual (I) and moving range (MR) charts are used for variables, measured one at a time per subgroup. These charts are respective plots of the values for single measurements, to monitor process location, and the range between two adjacent data points, to monitor the process variance. Single variable subgroups are common when measurements must be taken at prolonged intervals, or the measurements are destructive or expensive, or if the measures represent a single homogeneous batch.

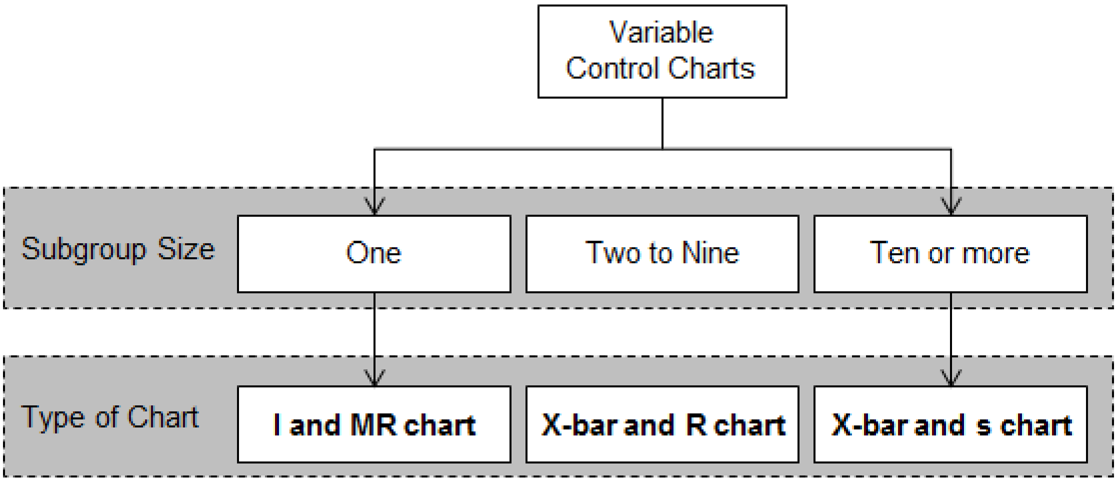


Figure 5.16: Variable control chart selection

5.5.4 Control chart structure

Different types of control charts are calculated and constructed in different manners, but all control charts have a common structure. There is an abundance of literature available that provides instructions on the construction of control charts and detailed analysis of control points to distinguish between causes of variation; therefore, this section focuses on the components that comprise control chart because it provides the information required to analyse and monitor improvement. The components that are studied for control analysis and revision are subgroups, mean, and control limits.

Subgroups are sets of measurements that represent a specific process characteristic over time. These sets are the foundation of control chart construction. The selection of rational subgroups is important to enable the isolation of special cause variation between subgroups while variation within subgroups is minimised. Rational selection may require a trial-and-error solution based on process knowledge and the following characteristics: number of subgroups, subgroup size, and subgroup frequency. [15]

The number of subgroups should be large enough to provide a realistic performance overview of the studied process. As a rule of thumb, the number of subgroups should be at least 25 for effective control chart calculations. On rare occasions fewer than 25 subgroups may be used as long as the control limits are recalculated when more data are obtained; but a control chart should almost never be attempted with fewer than 10 subgroups. Individual and moving range charts are an exception to this rule and requires at least 100 subgroups to be reliable, because each subgroup consists of only one value, and variation is based on observation-to-observation changes.

The subgroup size is the number of measurements that are produced under almost similar conditions within subgroups. It must be large enough to indicate out-of-control behaviour when a lack of control exists. The subgroup size for classification control charts is therefore often larger than required for variable control charts so that some nonconformances are likely to be included. Another crucial factor is the higher cost of larger subgroups; even though larger subgroups lead to more reliable control limits.

The subgroup frequency is defined as how often subgroups are selected. It requires experience and process knowledge to select a logical frequency because it depends on various factors such as the production rate, elapsed time, and shift duration. The frequency with which the subgroups are selected should minimise variation between batches, shifts, machines, or people. Frequent subgroup selection enables special variation to be captured, isolated, and analysed; but as the process is stabilised, less frequent subgroup selection is needed and resources can be focused elsewhere. [99]

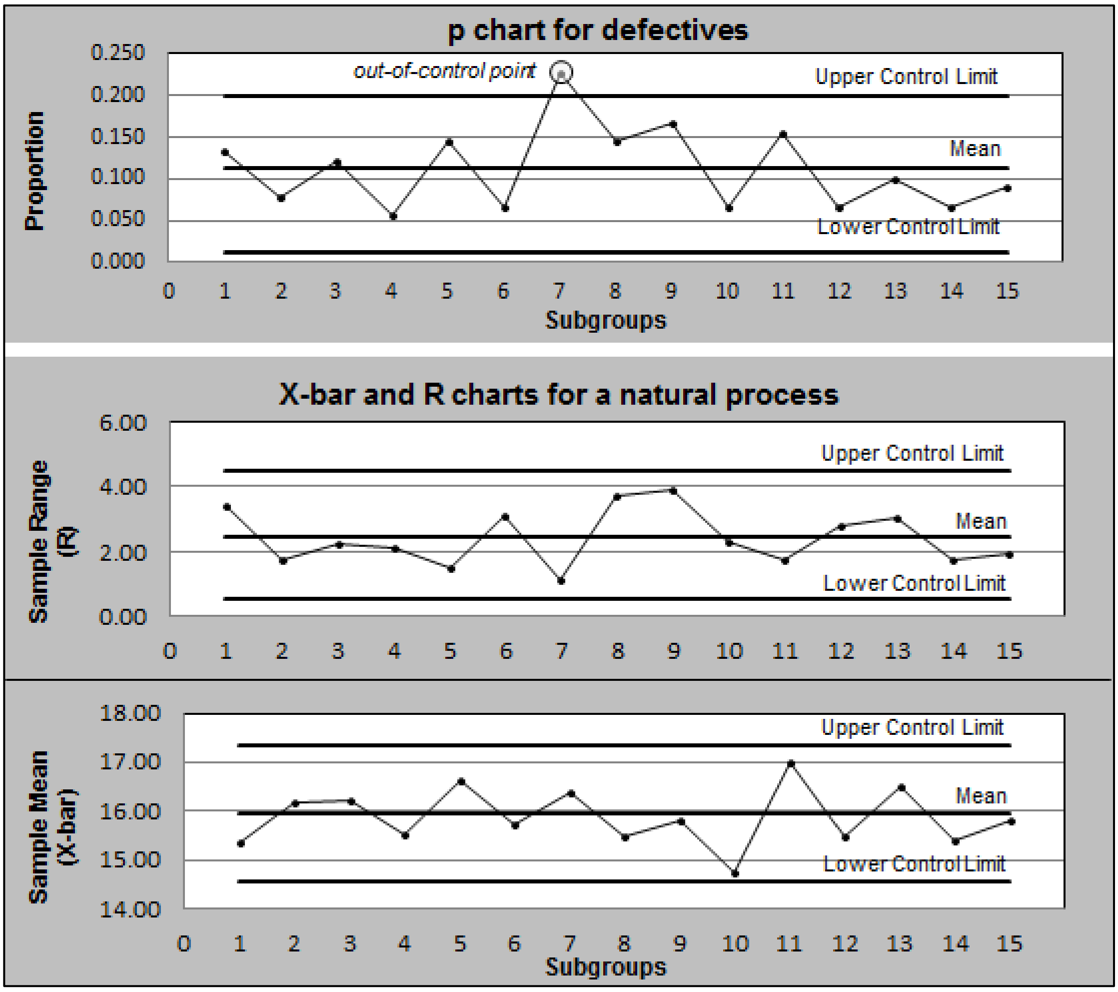


Figure 5.17: Control chart structure

The *mean* is calculated from the subgroups to provide a centreline for the control chart. It is an estimate for central tendency and is required for the calculation of the standard error used to determine the control limits. This is contrast to the run chart that uses the median as the centreline to neutralise the effect of very large or very small values. However, these values are required to calculate reliable control limits.

Control limits represent the limits of variation that should be expected from a stable process. Shewart proposed that control limits should be established at three times the standard deviation from the process mean; his research indicated that 99.73% of the common cause variation would fall within these limits. Subgroup averages are used as control points and compared to control limits to distinguish between causes of variation; a great deal of literature is available for detailed control point analysis.

Control limits are based on the average process variation within sample subgroups. It is therefore important to construct and analyse the variance chart first when variable data is studied; note that one chart is constructed and analysed when discrete data is studied. If the variance chart shows no indication of a lack of control, the location chart can be constructed and analysed. However, if there is an indication of a lack of control, the process is not stable and the control limits will also be unreliable and may not reveal special causes of variation on the location chart even when they exist. [98]

5.5.5 Analysis and revision

Remember that run charts are often adequate to identify general variation, but the formal statistical analysis of control chart provides more detail in situations where data are independent and normally distributed. The extra detail helps to differentiate between causes of variation and is important for the continuous reduction of variation to increase quality, and also customer satisfaction, in the future. Management should therefore define the purpose of control analysis to motivate the use of control charts.

Control analysis can start once a control chart is constructed and each component is thoroughly understood. The purpose is to recognise causes of variation and reduce the difference between customer requirement and process performance. This can be done with manual examination of the control chart or with software execution. Once causes of variation are identified it should be reduced or eliminated and standardised policies and procedures should be implemented to sustain improvement efforts. It is therefore crucial to include everyone that is affected through the studied process. [15]

The next step is the identification and isolation of special causes of variation, which either decrease performance or improve performance. Simple rules can be applied to determine if a process exhibits a lack of control. The basic rule is to look for data points that fall outside the control limits, because they are an instant indication that a process is out of control. A process is also considered unstable if the distribution of the data points is not random, even though each point falls within the control limits.

Once special causes of variation are identified it should be eliminated or incorporated by someone who has direct control over the process. Standardised guidelines should therefore be developed to provide corrective actions and support in the event of an out of control situation. The out of control data point that corresponds to the cause of special variation can be deleted and the control limits recalculated once the cause is eliminated. This cycle is continued until there is no more special cause variation.

When all the special causes of variation are eliminated or if none were found on the control chart, the process is considered to be in a state of statistical control; this is a basic requirement for further improvement. Focus can then shift to the reduction of common causes of variation through changes in the process itself. First, move the process average closer to the desired level. Second, management must reduce the level of common cause variation with the focus on continuous improvement. [90]

The dynamic nature of continuous improvement requires that control limits should be revised; but excessive revision of limits is adverse and inappropriate. Control limits should therefore only be recalculated for three reasons, which also require revision of the centreline. First, when special causes of variation have been eliminated and the out of control points have been removed from the data set. Second, changes in the process because of internal factors that influence critical parameters. Third, when enough subgroups become available to replace trial limits with regular control limits.

5.6 Theory of management

The six sigma management system promotes quality consciousness and provides guidance for six sigma implementation, which also includes the education of people in different functional areas to support systems thinking and to create awareness of their important role in process improvement. This management system can be traced back to the influence of W. Edwards Deming, whose management theory, the system of profound knowledge, provides the foundation for several modern quality concepts.

Deming developed the system of profound knowledge to signify the deep insight that comprehensive process knowledge offers into improvement; process knowledge is gained from experience and coordinated by theory to promote joy in work, which is important for breakthrough improvements because the metrics and methodology are not sufficient on their own to achieve sustainable results. This is based on a holistic and comprehensive theory of management that is suitable for most industries. [100]

5.6.1 Paradigms

Deming based his management theory on four common paradigms that force people to interpret data about different situations and develop the environment required to promote joy in work. These four paradigms represent a shift from the traditional belief system used by managers to create an environment for process improvement. [15]

Paradigm 1: People are best inspired by a mix of intrinsic and extrinsic motivation; not only extrinsic motivation. Intrinsic motivation is experienced by people through to the sheer joy of a work endeavour; management is responsible for the development of an environment that encourages the release of this internal human energy for the improvement and innovation of a system. Extrinsic motivation originates from the fear of punishment or the desire for reward; this restricts the release of intrinsic motivation through appraisal, judgment, and policies that can destroy the confidence of people.

Paradigm 2: Management should use both a process and results orientation when a process is evaluated. This allows them to define the capabilities of the process to predict future performance and make decisions based on scientific data, even though they should also consider unknown figures such as the benefits of a proud employee or the cost of an unsatisfied customer. Management should therefore encourage an improvement culture that focus on the process, and not just manage the results.

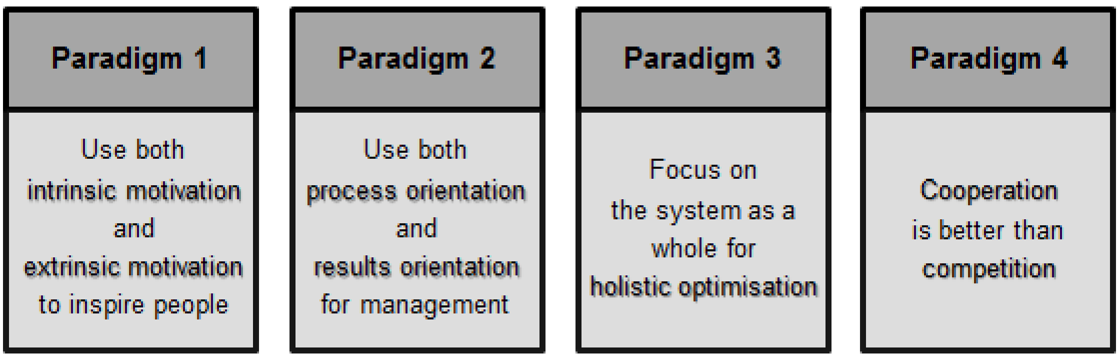


Figure 5.18: Paradigms of management

Paradigm 3: The function of management is to optimise the entire system, and not just the components of the system. They must understand that every system in the organisation is interdependent and that isolated improvement efforts can affect the system in a negative manner. Management must therefore focus on the optimisation of the entire system, even if it means that one or more components are suboptimised.

Paradigm 4: Cooperation is better for improvement than competition. Individuals that are forced to compete cannot reap the benefits of a win-win perspective, therefore most people lose. Competition is also expensive and costs include rework, waste, redundancy, reinspection, schedule disruptions, stress, and destruction of joy in work for individual endeavours. Cooperation is always the preferred paradigm when the aim of the system is to improve, but competition is preferred when the aim is to win.

5.6.2 Components

Deming defined his theory of management as the interaction between these related components: appreciation of the system, theory of variation, theory of knowledge, and psychology. Although the system is interdependent, expert knowledge of these components is not required to understand and use the theory of management. [32]

Appreciation of the system is the comprehension of the complex interaction between people and processes that work together towards a common purpose; the common purpose should be well defined to ensure effective alignment of the interdependent components of the system. Management is responsible to optimise the entire system toward this common purpose. They should also promote this purpose because it may require functional management to suboptimise some components; success depends on the integration of all the components and not the performance of individual parts.

Theory of variation refers to the interaction between the components of the system and its environment. Variation is discussed earlier in this chapter because of its direct influence on process performance. In brief again, variation is inherent to processes and can be categorised as either common or special. Common cause variation is a result of the inherent design and structure of the system and should be isolated and reduced by management; special cause variation is the result of external factors and should be resolved by people that are closest to the process. A system that does not exhibit special cause variation is stable; that is, it is in a predictable state of variation.

Theory of knowledge is the development of knowledge through a theory that is used to predict a future outcome, which is compared with the observed outcome, to decide whether to support, revise, or abandon the theory; knowledge is the quantifiable risk that the predicted outcome, as stated by the theory, will be wrong. The theory allows people to learn from the experience, which improve their appreciation of the process; experience alone is of no value without the aid of theory. Success can therefore not be copied from system to system based on experience alone; however, the theory that underlies success can be replicated when the success factors are understood.

Psychology is the appreciation of the human side of change and helps management to understand how people interact with each other and with the system. People have different preferences and learning styles that management must recognise and take into account. Different people also require different amounts of intrinsic and extrinsic motivation to drive their behaviour. Management should determine the proper mix of motivation for each person to commit them to change, rather than to rely on direct interpretation of their behaviour. Once change has been developed that is compatible with the current culture, people must be informed about the benefits and included in the solution; this culture must see failure as a result of bad systems, not bad people.

5.6.3 Points for management

The six sigma methodology can produce significant, innovative performance results when it is deployed by dynamic leaders that develop and enable people to participate in process improvement activities. Leaders must understand the interrelationships between themselves and their environment, which includes people and processes, based on an organisational wide perspective. This method is summarised in a set of 14 related points for management, which Deming developed to reflect his view on the strategic need for leadership to encourage a culture of continuous improvement. [101]

Point 1: Create constancy of purpose toward process improvement. Leaders must define vision and mission statements based on organisation values and beliefs. The vision statement seeks to communicate the desired future state of the organisation to the stakeholders. The mission statement serves to inform stakeholders of the current reason for the existence of the organisation. Values and beliefs are the principles that provide a framework for focused, consistent behaviour of the improvement culture so that participants understand their roles, and feel more secure, within the organisation.

Point 2: Adopt the philosophy of management and learn its responsibilities, focus on the customer, and take leadership for change. This point encompasses the paradigm shift that leaders have to accept if they strive toward a culture of continuous process improvement as a consequence of the management theory that Deming developed.

Point 3: Cease dependence on inspection as a means to ensure quality; eliminate the need for mass inspection and rather build quality into the process. The quality hierarchy provides three levels that guide the persuasion of predictable and reliable output: (1) defect detection, (2) defect prevention, and (3) continuous improvement.

Defect detection relies on mass inspection to detect and remove defectives, because defects in output are expected at this level of quality consciousness. Defectives are removed from the process without consideration of how to avoid defective output and decrease variation; there is no additional feedback that supports the identification of further improvement opportunities. Management must stop their reliance on mass inspection and seek to build quality into the process to prevent the occurrence of defects in the first place, because the cost associated with defects is unrecoverable.

Defect prevention strives to produce predictable output within specification limits and achieve zero defects. This level of quality consciousness assumes process output that falls within specification limits will meet customer requirements. People are therefore under the impression that they don't have to reduce variation when the process reaches a state of zero defect production. However, variation reduction and other improvement activities must continue to ensure the production of predictable output within specification limits because variation is inherent to processes, which means that even a stable process will deviate from specification limits in the long run.

Continuous improvement is the constant reduction of process variation, even within specification limits, to reduce the difference between customer requirements and process performance. Management must take action to move the process average closer to the desired value and reduce unit-to-unit variation; reliable and predictable processes must always be persuaded to compensate for inherent variation. Long terms decisions and strategic investments should therefore be considered to support continuous improvement activities, even at the expense of short term financial goals.

<table>
<tr><td colspan="2">kp rule: $\frac{k_1}{k_2}$</td></tr>
<tr><td>k_1: Inspection costs
• Capital equipment
• Labour
• Maintenance
• Rent & Utilities
• Piece cost (outside vendor quote)</td><td>k_2: Possible detrimental costs
• Repair cost
• Lost production cost
• Warranty costs
• Cost of unsatisfied customers
• Lawsuits (k_2 = ∞ for safety items)</td></tr>
<tr><td colspan="2">p: fraction of defective items</td></tr>
<tr><td colspan="2">Interpretation of kp rule</td></tr>
<tr><td>$\frac{k_1}{k_2} > p$</td><td>0 percent inspection</td></tr>
<tr><td>$\frac{k_1}{k_2} < p$</td><td>100 percent inspection</td></tr>
<tr><td>$\frac{k_1}{k_2} = p$</td><td>either 0 percent or 100 percent inspection</td></tr>
<tr><td colspan="2">Note that this is just a guideline because k_2 can sometimes be difficult to estimate.</td></tr>
</table>

Figure 5.19: The kp rule for inspection

Deming advocated a rule that facilitates the collection of process data to support the continuous reduction of variation and let quality consciousness progress from defect detection to continuous improvement. This analytical rule, called the kp rule, is based on statistical evidence and can be used to minimise the cost of inspection and its effect on the process through either no inspection or 100 percent inspection given a stable process; sample inspection is not effective when a process is stable, so it is not an option. This rule can be applied between any two process points, except when inspection is destructive or when samples are taken from a homogeneous mixture.

It is important to understand that a lack of inspection does not mean zero process information. Small samples should always be drawn from batches for information about the process. This information should be analysed with tools such as control charts to facilitate process improvement. The cost of these small samples is part of operational cost and is therefore not considered in the cost function to be minimised.

Point 4: Do not award business on the basis of price tag; instead, focus on lowest total cost and establish long-term relationships with suppliers based on loyalty and trust. Suppliers and buyers form part of an interrelated system and must therefore be optimised as a whole; so avoid suboptimisation. Management must understand the procurement scenarios to optimise this system. These are summarised in Table 5.3.

Table 5.3: The three procurement scenarios

Scenario 1
• Several suppliers meet the exact requirements; the only difference is the price • In this scenario it makes sense to base purchases on *lowest price*
Scenario 2
• Several suppliers meet the exact requirements, and prices are identical • In this scenario it makes sense to base purchases on *best service*
Scenario 3
• Several suppliers tender different proposals at different prices • In this scenario a decision will be difficult

The third scenario requires careful and extensive research to select the appropriate supplier from several suppliers that tender their proposal in different ways and quote different prices. It makes therefore sense that customers and suppliers enter into long-term relationships based on trust and statistical evidence of quality. This type of relationships promotes continuous improvement to establish more predictable and reliable systems at a lower cost. Management should focus on the improvement of current relationships before they seek to develop new or additional relationships. [15]

Point 5: Strive towards a culture of continuous process improvement. Focus on the system in terms of process flow, inputs, supervision, maintenance, quality, and the integration of human resources to optimise the system as a whole. The development of such a culture requires the implementation of statistical and behavioural methods.

Statistical methods are needed to differentiate between special and common causes of variation. Management must use this information and create stable processes with predictable and reliable output to determine the future state of the system that can be achieved with improvement efforts. Basic process optimisation techniques such as the 5-S movement and the SDSA standardisation cycle can be used to initiate these improvement efforts; also use the PDSA cycle to manage and sustain improvements.

Behavioural methods refer to empowerment of employees to encourage a culture of continuous improvement. Empowerment provides people at the lowest appropriate level in an organisation with the authority to make decisions. The aim is to increase joy in work, encourage people to take calculated risks, and motivate them to take action and obtain results through hard work. This starts with leadership, but requires commitment of employees. These associated responsibilities are listed in Table 5.4

Table 5.4: Empowerment: associated responsibilities

Management must provide employees with:
• The opportunity to define and document the key processes. • The opportunity to be educated and trained. • The opportunity to improve best practice methods that make up systems. • The latitude to make decisions within the context of best practice methods. • An environment of trust without judgment
Employees must be responsible to:
• Train their skills and increase their knowledge of the system. • Participate in the improvement and standardisation of best practice methods. • Utilise their latitude to make decisions within best practice methods.

Best practice methods can consist of either generalised procedures or individualised procedures. Generalised procedures provide employees with standardised methods that they must follow and manage through team activities. Individual procedures provide employees with the opportunity to use their individual differences to manage procedures on their own, on condition that output of the individualised procedures is standardised across individuals; this requires organisation wide cooperation. Each employee must resolve problems within the context of the best practice methods at operational level; they should not change the best practice method on their own. [15]

Point 6: Management must ensure that employees are trained in their current job to improve their performance. Employees are an important asset of organisations and should be empowered to improve their job skill and take joy in their work. This is achieved through training on the job to either introduce a new behaviour, or change their current behaviour so that a particular kind of improved behaviour takes effect.

Management must track the current distribution of job skills and then consider the speed at which employees learn so that they can improve the future distribution of job skills. They should utilise statistical methods that indicate when an employee reaches a state of statistical control with respect to a job characteristic. If the work performance of an employee is not in statistical control (unstable), the employee will benefit from more of the same training. However, if the work performance of an employee is in statistical control (stable), then the employee has learned everything from the training program and more of the same type of training will not be beneficial.

Point 7: Institute a leadership structure that integrates people with the system and enable them to improve the system within the context of best practice methods. A leader must understand and manage the interrelated components of the system to achieve a common goal. Leaders must therefore be able to prioritise application of resources to optimise the system even if it requires that some system components are suboptimised. Furthermore, leaders must continue to invest in education because experience without theory does not enable learning or the prediction of future events.

Point 8: Drive out fear in people and encourage them to pursue everyday process improvement activities. Management can remove the source of fear because it is known, unlike anxiety, in which case the source is unknown. Common sources of fear includes a lack of job security, ignorance of company goals, poor supervision, lack of operational definitions, limitations in training and education, an environment without trust, and inadequate work procedures. Individuals that are exposed to these conditions experience poor morale, reduced creativity, poor performance, reluctance to take risks, poor interpersonal relationships, and reduced motivation. Management must therefore create a fear and judgment free environment to promote joy in work.

Point 9: Strive to break down barriers between departments and adapt a process orientated management perspective. Barriers between departments prevent the much needed cooperation and communication that are essential to integrate the components that comprise the system. Management must understand how these components interact and encourage cooperation between functions to optimise the system as a whole. Incentives for isolated optimisation must therefore be eliminated.

Point 10: Eliminate slogans, exhortations, and targets that tend to be divisive and counterproductive to any group of people within the organisation; management must provide people with operationally defined statements that will motivate individuals and explain expectations. Statements that do not represent a plan or method to achieve the expressed goal can create adversarial relationships. Such general statements only show management’s wishes for a desired result and do not provide employees with practicable solutions. This leads to an environment of resentment without trust where employees are not empowered or able to make improvements to the system.

Do it right the first time

Right place; Right time

Safety first

Continue to improve

Zero defects

Figure 5.20: Slogans that must be avoided

Point 11: Implement leadership as a substitute to numerical management. Arbitrary numerical management can be a disincentive to performance, reduce total quality, discourage productivity, and increase waste. Two types of numerical management that are most often used to coordinate operations are work standards and objectives.

Work standards provide employees with an expected level of performance based on specified values that have no association with the capabilities of the process. These do not guide improvement efforts and employees get blamed for problems beyond their control. This deprives them of joy in work, especially if standards are too high or too low. Standards that are set to high increase pressure on employees and result in defects, which diminish morale and motivation; on the other hand, standards that are set too low lead to idle employees and process losses. Management should therefore base expectations on process capabilities as determined through statistical methods.

Objectives based on arbitrary numerical values are used to break down projects into smaller sections. They do not provide new tools, resources, or methods to achieve the objective. Employees may therefore need to abuse the system to meet the goal, but this abuse may cause the system to fail elsewhere because of uneven resource distribution; employees are then held accountable for failure, which reduces pride in workmanship. Objectives, resources, and methods form an interdependent system that management must consider, before the organisation of system components and allocation of resources, to optimise the strategic objectives of the system as a whole.

Point 12: Remove barriers that deprive employees from their right to pride and joy in workmanship. This means the abolishment of traditional methods based on annual performance appraisals and of management by objectives. Performance evaluation and reward must be based on quality, which should be driven by personal pride. This promotes joy in work and motivates employees to improve quality and performance.

Table 5.5: Typical barriers that deprive employees from joy in work

#	Barrier
1	Unclear expectations with respect to organisational objectives
2	Work standards that force employees to follow rigid procedures
3	Employees that are blamed for problems that are out of their control
4	Rapid design of products without proper, tested prototypes
5	Lack of training and education to develop knowledge of the system
6	Defective equipment and material; unreliable methods and procedures
7	Management systems that focus on results, and not the entire process
8	The traditional, biased performance appraisal management approach

Point 13: Institute a dynamic program of education and self-improvement. This is the continuous investment in employees to develop and grow their inherent potential to participate in improvement. Employees must be developed as both professionals and individuals, because their intellectual property is of primary organisational value. This should be attempted with internal resources, but outside expertise may be required for complex situations and the development of leaders. Remember that education is designed to improve the competence of a person beyond the job now held; on the other hand, training is used to exploit inherent talent and improve a specific job skill.

Point 14: Commit to change and take action to accomplish the transformation. This requires an action plan and the cooperation of affected people to achieve the vision of a six sigma organisation. Management must expand and stimulated the energy that drives the transformation; this energy can originate from different sources such as a crisis or a vision. To be able to plan, control, and improve the transformation, management must know how people will experience the transformation and how these experiences will interact with each other and with the aim of the transformation.

These 14 points of management provide a strategic framework for transformation from the traditional paradigm of management, to system of profound knowledge based management. The traditional management paradigm was developed through the addition of various improvement concepts that do not consider the relationships between the interdependent components of the system; but the system of profound knowledge enables leadership to understand the relationships between the people, systems, and environment. The system of profound knowledge is based on a holistic and comprehensive theory of management, which is suitable for most industries. [15]

6. Theory of Perspective: A roadmap for continuous improvement

Small businesses are important contributors to economic and socioeconomic growth in South Africa. However, these businesses struggle to survive and achieve financial success within the current competitive environment; this is clear from the high rate of business failures. Businesses success depends on the ability to react and adapt to this environment that continues to change. This must often be achieved with limited access to finance, which makes it difficult to hire external consultants and to acquire new technology. Improvement must therefore be executed with internal, available resources; so future success depends in effect on the skill of resource application. [7]

The skills that are required for resource application towards improvement consist of managerial skills and technical skills. Managerial skills are needed to create a culture that strives to achieve process perfection through systematic solution generation and execution; Technical skills are needed for actual implementation of various tools and technique to execute improvement. However, small businesses in South Africa often suffer from a lack of skills and are therefore oblivious to the need for change and the identification of improvement opportunities. These skills must therefore be developed and improved through knowledge and experience in improvement methodologies. [8]

Improvement methodologies provide the principles, strategies, techniques, and tools that are required for successful process improvement. This report discussed lean thinking, theory of constraints, and six sigma thinking. Each of these methodologies provides a different approach to process improvement, as summarised in Table 6.1.

Table 6.1: Improvement methodologies summary

	Lean Thinking	Theory of Constraints	Six Sigma Thinking
Principle	Remove waste	Alleviate constraints	Reduce variation
Focus	Value focused	Throughput focused	Quality focused
Guidelines	1. Identify value 2. Value stream map 3. Create flow 4. Establish pull 5. Pursue perfection	1. Identify constraint 2. Exploit constraint 3. Subordinate operations 4. Elevate constraint 5. Avoid inertia	1. Define 2. Measure 3. Analyse 4. Improve 5. Control
Result	Value for the customer	Faster system throughput	Stable processes
Criticism	No statistical analysis	Accepts process variation	Independent actions

There is an abundance of literature available on these methodologies, and yet some people struggle to implement the strategies into their organisations. The problem is that terms such as “lean”, “kanban”, “bottleneck”, “flow” and “variation” have become corporate buzzwords that people address without sensible consideration of a specific situation; then, when the approach fails because of incorrect implementation, many people conclude that the approach does not work in their organisation. Furthermore, people attempt to replicate approaches that were implemented with relative success in a different situation; this can also lead to failure and discourage improvement. [16]

Selection of appropriate tools and techniques can be difficult because of this partial, distorted perception that some people have about improvement. Furthermore, each of these three improvement methodologies has their own respective advantages and disadvantages, which determine their relevance to specific situations. Even though there are many differences between them, the methodologies can co-exist if their principles and strategies are understood. The common foundation for success is that these methodologies strive to enhance the perception of improvement, and educate people on perspective, in order to achieve and sustain real process improvement. [52]

At this point it is important to understand the basic difference between perception and perspective. Perception is the manner in which something is regarded, understood, or interpreted; this is based on what one feels to be true even without the appropriate knowledge or rationale. People observe situations and interpret the actions of other people, based on their own experience, culture, and values to create their perception, which can be distorted. This perception is the set of beliefs that defines how people understand processes and make decisions. The manner in which people approach improvement can therefore be enhanced with the development of perception. [102]

On the other hand, perspective is a point of view, which is used for the subjective evaluation of something to determine its relative importance. This is based on a particular attitude that enables people to think about a situation or problem in a wise and reasonable manner and to perceive aspects of a subject with the appreciation of their actual interrelations with each other and to the subject as a whole. Perspective also contributes to the development of values and beliefs that form the perception of people. Therefore, perspectives can be used to develop the perception of people towards process improvement. This report calls this the “theory of perspective”. [103]

The theory of perspective is a holistic approach that considers the comprehensive interdependencies within organisations. This is based on the appreciation of different perspectives that represent continuous process improvement as an organisational wide approach. These perspectives provide a synergetic reflection and interpretation of continuous improvement aspects to create a perception that can guide actual, successful improvement activities. Therefore, the theory does not focus on direct process improvement, but on improvement of how people perceive the process, so that they can improve it themselves; nevertheless, direct improvement is the result.

This theory provides the foundation for the development of a systematic, proactive roadmap that provides skill constrained small business managers with directions toward internal, sustainable process improvement without support from external specialists. The directions are discussed in terms of different perspectives at different levels. Once these are understood and applied to make successful decisions it is considered to have corrected distortions and enhanced perception of improvement.

The roadmap does not attempt to construct a new science or expand on available methodologies; direction provided through the roadmap is used to supplement and integrate current ideas, and not replace them. These ideas are categorised into two categories: strategic support and technical support. Strategic support is the framework of the roadmap itself, as well as the strategic and tactical decisions that drive process improvement activities. Technical support is the statistical analysis and process optimisation tools that are used to execute strategic and tactical decisions.

When the roadmap is studied it is crucial to focus on the intent of each perspective, and not the tools, because the tools can be interchanged to support the intent. The technical tools, as well as advanced technologies, must also be used to supplement the roadmap, and not to replace the strategic support. Technology is often used as a substitute for thinking; but improvement is first a way of thinking, then a way of doing.

There is no time allocated to the perspectives, because continuous improvement follows an incremental approach, which must consider all the perspectives at the same time to improve the organisation as the business environment changes. So the perspectives are not time-bound, but must first be studied in the provided sequence to develop people's perception of improvement. Thereafter, the perspectives must be used to provide a holistic overview of improvement for the organisation as a whole.

Another aspect of the roadmap is that it focuses on internal improvement, because this is where management can exercise the most control. The final aspect is that the roadmap follows an incremental approach to guide managers through nine crucial perspectives without information overload. These are categorised into organisational perspective, primary process perspective, and secondary process perspective.

6.1 Organisational perspective

The organisational perspective provides management with a high level overview of the organisation as a system. This is the point where management must commit to change with an objective attitude towards the different perspectives. The roadmap provides various insights that can be adopted for improvement, but they must be applied in a manner that fits with the values of the organisation and technical context.

The roadmap focuses on process improvement; but processes form part of a larger system, which is an interdependent network of people and processes with a common purpose. The system must therefore be improved as a whole in order to improve the process. However, improvement actions often results in failure because management support is absent, employees are not involved, or processes are not stable. These aspects must be understood for improvement, so organisational perspective is further arranged into philosophy perspective, people perspective, and process perspective.

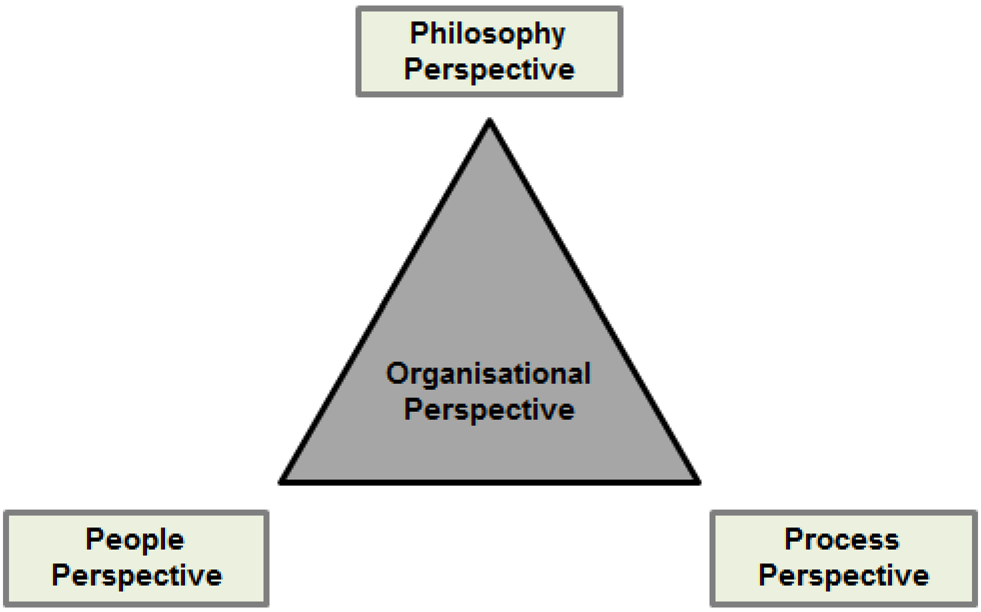


Figure 6.1: Organisational perspective

6.1.1 Philosophy perspective

The philosophy perspective deals with the alignment of the organisational strategies that drive current and future operations and improvement activities. This perspective provides the foundation to rationalise and encourage long-term investment in the management and development of the organisation as a system; so the philosophy must be understood to gain support from top management for improvement activities, and to ensure that the employees and resources work toward a common purpose.

Phase 1: Constancy of purpose

Most organisations have an isolated purpose (goal), which is often to make profit, but profit is the result and the result alone is not enough to encourage commitment of people toward improvement. Actual commitment towards improvement requires a constancy of purpose that promotes a culture and environment in which affected people can contribute to the purpose; constancy of purpose is based on the strategic responsibilities of people and is described in the vision and the mission statements.

The vision statement seeks to communicate and inspire a desired future state of the organisation to stakeholders. The mission statement serves to inform stakeholders of the current reason for the existence of the organisation. These statements must be based on the values and beliefs of the organisation to provide a common foundation for focused and consistent behaviour of an improvement culture, in an environment where participants understand their roles to feel more secure within the organisation.

Phase 2: Long-term strategic management

Constancy of purpose calls for long-term commitment to continuous improvement and organisational wide participation to achieve the purpose. Patience is required because continuous improvement is an incremental approach that strives to develop the organisation and accomplish the desired future state as described in the vision statement. The vision must always be considered when decisions are made; even when a crisis initiates improvement, solutions must be based on long-term strategies.

Management can sometimes be forced to make decisions even at the expense of short-term financial goals; decisions must always support organisational growth and the alignment of people and resources towards the desired future state. This shows dedication to employees and secures their place in the future of the organisation, which encourages them to commit to the development of an improvement culture.

Phase 3: Continuous improvement culture

People tend to seek perfection when improvement activities are developed. This is known as the utopia syndrome, and is an inhibitor of continuous improvement. The search of perfection slows down execution of improvement activities and it also leads to fear of failure. However, people must embrace the risk of failure as an opportunity to learn and develop new solutions; frequent small changes with the risk of failure are considered better than stagnation without risks. This approach requires a culture of continuous improvement to support and execute incremental improvement activities.

Cultural change takes time and requires development of the perception that people have about incremental improvement. Even though cultural change is not the explicit focus of this roadmap, the methods that are discussed do contribute to a change in the culture. Experience in the responsibilities for continuous improvement can also strengthen the culture itself. The culture is responsible to understand the systems, make decisions through consensus, solve problems, and reflect on their actions.

The systems within the organisation must be understood to enable identification and analysis of problems and improvement opportunities. Direct observation is important to understand the actual situation at operational level. Even top management must practise direct observation because remote analysis on basis of theoretical standards or reported data does not always provide a true reflection of the actual situation.

Once the system is understood at operational level decisions can be made with regards to improvement. These decisions must include the affected people and consider several options for improvement. This approach broadens the solution base and gives participants ownership of ideas; however, this can consume a lot of time.

The culture must also strive to solve system problems as part of improvement. This approach relies on reactive actions and fundamental actions. Reactive actions are required to maintain the system at its current level of performance; and fundamental actions are required to improve the system beyond its current level of performance.

After improvement actions are executed, reflection must be used to learn from the experience. Even when actions resulted in failure, reflection can be used to develop effective countermeasures. The act of reflection is considered an attitude that is both an enabler and result of successful improvement actions and forces people to learn.

6.1.2 People perspective

The people perspective deals with the development of the people in the organisation and also the improvement of their work environment. People are an important asset of the organisation and must be managed to exploit their inherent skill and intellect; underutilisation of skill and intellect is a fundamental waste. Therefore, investment in their development is vital to enable their successful participation in management and improvement activities. However, before people can be included in the system their values and beliefs must be aligned with the values and beliefs of the organisation.

The development of people, and their work environment, is also required to prepare them for improvement. Management often focuses on only the tools and techniques required for improvement because of their isolated perception of improvement as a technical issue; however, the tools and techniques do not ensure success, it is the people who use the tools and techniques who must ensure success. Therefore, the people development focuses on the technical and the social aspects of improvement.

Phase 1: Pride and joy in workmanship

Pride and joy in workmanship is important to increase morale and performance. The organisation must therefore emphasise openness, which encourages the free flow of ideas and innovation to develop responsible and loyal people who want to contribute to improvement. The creation of an open organisation is initiated through the removal of barriers that deprive people from their right to pride and joy in workmanship.

Several barriers can inhibit the development of people within the organisation. One significant example is work standards; other barriers are discussed throughout this roadmap where appropriate. Work standards, not to be confused with standardised work, provide targets based on the current method, which is not always the most efficient method. These targets often provide numerical goals without the means to achieve the goals, which can lead to culture of competition rather than cooperation.

Cooperation is better for continuous improvement than competition, because people who cooperate share their knowledge and experience in order to learn from each other, which is not possible through competition. The foundation for cooperation is an environment of trust, mutual respect and encouragement; these are also crucial for team based activities. Cooperation is always preferred when the aim is to improve; competition is preferred when the aim is to win, which is often a short-term solution.

The final aspect of pride and joy in work is motivation. People are inspired by both intrinsic and extrinsic motivation; not only extrinsic motivation. Intrinsic motivation is experienced through the sheer pleasure of a specific work endeavour; management is responsible for the development of an environment that fosters intrinsic motivation for continuous improvement activities. Extrinsic motivation originates from the fear of punishment or the desire for reward; this restricts the release of intrinsic motivation.

Phase 2: Knowledge, collaboration, and leadership

At this point people must be motivated and encouraged to increase their knowledge of the system in order to support appreciation of the system and the interpretation of experience. Knowledge can be increased through training and education. Training is designed to introduce a new behaviour or change the current behaviour in order to improve the performance of the current work methods. On the other hand, education is designed to improve the competence of people beyond the current work methods.

Collaboration is considered one of the most important qualities in people; therefore, trained and educated people must form cross-functional teams. This means that people must be able to step outside their designated areas to support fellow team members. Collaboration requires that people are cross-trained through job rotation in order to create flexible teams, which coordinate work and knowledge. Job rotation also creates focused, involved and motivated people who can perform different work.

Leaders should be selected from the teams to promote the organisational philosophy, support operations, and teach other people. This internal selection approach ensures that leaders understand the system at operational level, and it also encourages other people to grow and develop their skills. Even though leadership is a crucial factor for success, a complex leadership hierarchy is not needed because other people must be empowered to perform some of the traditional tasks that are assigned to leaders.

Phase 3: Empowerment

Empowerment provides people at the lowest appropriate level of the organisation with the authority to use their own judgment and make decisions within the context of best practice methods. Although empowerment starts with leadership, it relies on the commitment of the people closest to the process. Empowerment is an inherent part of this roadmap and crucial for improvement; management must therefore encourage people to make improvement suggestions and execute basic improvement activities.

6.1.3 Process perspective

The process perspective deals with the interdependent and interrelated operations that consume resources (time, machines, equipment, labour, and the environment) to transform inputs (data, materials, and components) into outputs toward a common goal. These operational steps can be defined, documented, analysed, and improved.

The problem with process perception is that people often think of processes in terms of production, but processes exist in every function of the organisation. First, core processes create physical products or services, which must be distributed to the customer. Second, support processes control resources and the infrastructure that the core processes require for operation. Third, management processes are used to control other processes to ensure effective and efficient operation. Management is responsible to optimise the three different kinds of processes toward a common goal.

Phase 1: Process orientated view

The traditional functional orientated management view relies on a formal hierarchical structure that strives to manage and optimise individual function or operations. This approach enables people to specialise in a specific field of expertise, which requires a larger workforce in order to cover all function. Furthermore, the optimisation of individual functions can lead to suboptimisation and harm the system. Therefore, a different management view is required for the holistic optimisation of the process.

Holistic optimisation of the system needs a process orientated management view that relies on knowledge of operational interdependencies to align customer requirements with process specifications. This view focuses on what needs to be done and how to do it within the boundaries of organisational values and beliefs. Management must break down barriers between functions to create flexible processes that encourage cooperation, communication, and cross-functional optimisation of the entire system.

Phase 2: Appreciation of the system

Appreciation of the system is the comprehension of the complex interaction between the people and processes that work together toward a common goal. Management must understand and integrate the interdependent components of the system, which can lead to suboptimisation of individual components in order to optimise the system as a whole. Therefore, appreciation of the system focuses on the process and the results; not only results. This appreciation can be improved with visual management.

Visual management must be implemented to create transparent processes, with no hidden problems. Transparent processes are important to communicate information to a large group of people at once. The purpose of this is to affect the behaviour of people and improve their appreciation of the system in order to commit them toward improvement. Visual management is often implemented through charts, graphs, and poster that show the relevant information at the relevant locations. These must be maintained with updated information to act as focal points for performance reviews.

Phase 3: Stable processes

A stable process is a basic requirement for process improvement; a stable process is defined as one that is capable to produce consistent results over time. Advantages of this include predictable performance, accurate improvement measures, and a more flexible process that can adapt to varied customer requirements. An unstable process can be indicated through direct observation of inconsistent work methods and a high degree of variation in process performance. High variation in a process can occur because there are no standardised work methods, and the amount of time it takes to perform a specific operation varies from person to person, across shifts, or over time.

Standardisation is the first step toward direct process improvement. Standardised work enforces stable and repeatable methods with the aim to maintain constant and predictable process outputs. The people closest to the work must be empowered to use the SDSA cycle in order to contribute toward standardisation because of their experience and knowledge of the specific process. This also encourages consistent behaviour and performance of people throughout the organisation. Standardised work must always be improved through the development of more efficient methods.

The antithesis of standardised work is variation. Unstable processes are the result of high variation and must be standardised to be improved. However, the definition of variation implies that a process is not able to be standardised. This paradox makes it seem that the improvement of unstable processes is impossible, but this just means that unstable processes must be improved with an incremental cycle that isolates and removes some variation through the implementation of new methods, the new methods are then standardised, and the cycle is repeated with a smaller focus. Every time the cycle is repeated a new baseline is created to distinguish between standard work and nonstandard work. Visual management can be used to support this cycle.

6.2 First intermission: Reflect and prepare

The purpose of this intermission is twofold. First, management must ensure that the people and the processes are aligned toward the philosophy. Second, management must prepare the PDCA cycle for actual improvement implementation. The methods that are mentioned to support each perspective are discussed in the literature study.

6.2.1 Reflect on the organisational perspective

At this point management must believe in a long-term commitment toward continuous improvement in order to realise constancy of purpose. Systems must also be in place for the development and empowerment of people. Furthermore, people must have an appreciation of the system and also understand the importance of stable processes.

Table 6.2: Summarised organisational perspective

Perspectives	Phases
Philosophy	1. Constancy of purpose 2. Long-term strategic management 3. Continuous improvement culture
People	1. Pride and joy in workmanship 2. Knowledge, collaboration, and leadership 3. Empowerment
Process	1. Process orientated view 2. Appreciation of the system 3. Stable processes

6.2.2 Prepare the PDCA cycle

The PDCA cycle is fundamental for the implementation of the perspectives discussed throughout the rest of the roadmap. The methods (tools and techniques) in the PDCA cycle are flexible; so when the cycle is executed it is crucial to focus on the intent of each step, and not the methods, as these can be interchanged to support the intent.

The PDCA cycle is discussed in detail in Chapter 6. Furthermore, six additional tools and techniques are included in order to enhance the cycle. First, the six thinking hats technique can be used in order to support idea generation. Second, measurement system analysis must be considered to ensure stable, unbiased, linear, impartial, and precise data collection. Third, Pareto analysis is an extension of a histogram. Fourth, reflection must be used in order to learn from pilot improvement. Fifth and six, visual management and standardisation must be implemented to maintain improvements.

Table 6.3: Summarised PDCA cycle

Steps	Methods (tools and techniques)
1. Select the focus area	• Process selection model • Impact analysis matrix • Define boundaries
2. Select the team	*Cross-functional teams* • Cooperation • Collaboration
3. Problem identification	• Flowchart • Cause-and-effect diagram • Five why's
4. Define objectives	• SMART objectives • Gantt chart
5. Plan improvement	*Idea generation* • Brainstorming • Affinity diagram • Six thinking hats (additional) *Idea prioritisation* • Multi-voting • Nominal group technique • Pairwise ranking *Force field analysis* • Force field analysis
6. Data collection	• Operational definitions • Data collection plan • Data collection forms • Measurement system analysis (additional)
7. Pilot improvement	• Keep it as small as possible • Include different conditions • Use data collection to monitor execution
8. Data analysis	• Numerical analysis • Histogram • Run chart • Pareto chart (additional)
9. Review improvement	• Reflection (additional)
10. Adopt or adapt	• Standardisation (additional) • Visual management (additional)

6.3 Primary process perspective

The primary process perspective provides an overview of the critical process aspects as defined by the final customer and the process itself. This perspective forms part of the organisational perspective and must therefore be approached with a philosophy, empowerment, and appreciation of the system. The organisation perspective drives the critical process aspects, which are derived from the improvement methodologies discussed in the literature study. These aspects are value, throughput, and quality.

Value is inspired by the lean thinking approach that strives to increase value faster than cost is accumulated, with the focus on continuous waste elimination; throughput is inspired by the theory of constraint, which states every system consists of multiple dependent operations and one of these acts as a constraint to the entire system; and quality is inspired by the six sigma thinking approach that strives to achieve a stable 6-sigma process, which produces no more than 3.4 defects per million opportunities.

Although each of these critical process aspects is inspired by a specific improvement methodology, the aspects themselves are based on integration of the components of these methodologies. The similarities between each of the components are exploited, while the differences are compromised to benefit the system as a whole. Individual appreciation of each aspect is a crucial prerequisite to understand the interrelations between the three process aspects. Therefore, primary process perspective is further arranged into value perspective, throughput perspective, and quality perspective.

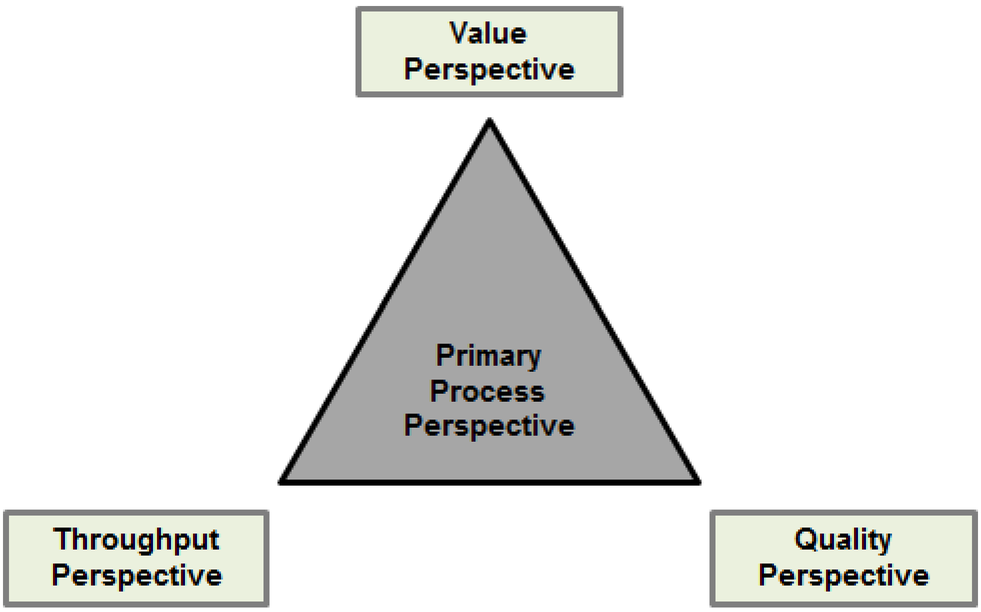


Figure 6.2: Primary process perspective

6.3.1 Value perspective

The value perspective deals with customer perceived value added activities. This perspective is to the process as philosophy is to the organisation. The purpose of value addition and creation is to provide the final customer with what is requested, when it is requested it, in the format that it is request. Value can therefore be added or created in terms of time, place, or form. All the improvement activities must focus on these aspects of value with the purpose to increase customer satisfaction, and to eliminate or reduce the activities that does not add or create value. Feedback from the final customers is therefore important to understand their perception of value so that the organisational resources can be aligned to achieve customer expectations.

Phase 1: Value stream creation

The long-term success of an organisation depends on its ability to meet the needs of its customers based on their perception of value. When the process serves various customers, improvement activities must focus on the customers that provide the most revenue. The needs of these customers must be identified, as well as the processes that create or add value to achieve those needs. Customer feedback can come from reactive sources, such as customer complaints, sales information, technical support, warranty claims, and returns; on the other hand, proactive sources can also provide additional information from interviews, surveys, market research, and observations.

Once the customers are identified a SIPOC analysis can be executed to document the process that serves these customers. This high level process map can be further refined with a flowchart. The flowchart must then be used to analyse the operations in terms of their contribution to value. First, determine what operations are required to create or add actual value to the product. Second, determine what operations do not create or add value, but are required to support the value added operations; these include operations such as maintenance and administration. Third, determine what operations do not create or add value, and are not required to support value added operations. These non-value added operations are wasteful and must be eliminated.

Phase 2: Extended 5-S movement

After the wasteful operations are eliminated, improvement focus must shift to waste within the value added, and non-value added but required, operations. There are certain fundamental concepts such as orderliness, cleanliness and discipline, which can be implemented through the 5-S movement to initiate waste elimination activities.

The 5-S movement combines the collective talents of people in order to encourage a culture of improvement with the empowerment of individuals and small groups. This approach is often demeaned because it is so simple, but a simple approach is ideal to empower people and let them contribute to the organisation through suggestions and the implementation of practical and low cost incremental improvements. The five elements of the 5-S movement are sort, set in order, shine, standardise, and sustain.

The extended 5-S movement has an additional element: simplify. Before the usual five elements are executed, the operations must first be simplified in order to ensure that the focus of the 5-S movement is on the appropriate activities. Simplification is used to challenge the activities in order to determine what activities can be eliminated or combined, how the sequence or location of activities can change, if it is possible to remove the person that does the activities, and how these activities can be improved.

Phase 3: Throughput accounting

Dr. Eliyahu Goldratt identified throughput, investment, and operating expense as the three basic measures that can be applied across organisational functions to monitor improvements. These measures can also be used to calculate net profit, return on investment, and productivity. The goal of most organisations is to increase net profit, which is calculated as throughput minus operating expense; throughput is calculated as sales minus total variable cost, and operating expense is calculated as all the expenses used to transform inventory into throughput, minus the cost of raw material.

The calculation of net profit shows that there are two opportunities for improvement: either increase throughout or reduce operating expense. Waste elimination activities are therefore executed to focus on the reduction of operating expense and inventory, which is a variable cost. However, waste elimination activities focus on a finite pool of resources and can lead to capacity cutbacks. These activities can also discourage cooperation because people are expected to do more work with fewer resources.

Net profit should therefore be increased with throughput, and in effect value creation, which has a theoretical potential for infinite growth. Operating expense and inventory must first be used to protect throughput. So once the minor wastes are reduced with the 5-S movement, improvements must focus on the constraint that limits throughput.

The PDCA cycle must be executed at least once for the perspective to be completed.

6.3.2 Throughput perspective

The throughput perspective deals with the alleviation of system constraints to ensure maximum rate of production. The system can be viewed as a chain of interdependent links that work together toward a common goal. Overall performance of the chain is governed by the strength of the weakest link. Therefore, improvement activities that do not focus on the weakest link are considered to be wasteful. This is important to understand because organisations consist of complex systems with an almost infinite number of improvement opportunities, which must be executed with a limited amount of resources; resources must therefore be focused on the fundamental opportunities.

The chain analogy provides inherent prioritisation of the fundamental opportunities, because the weakest link must always be the focus of improvement activities. This link is known as the constraint and is responsible for the prevention of maximum process throughput. The constraint can either be external or internal, but external constraints such as the vendor or market are not within the scope of this roadmap; internal constraints are located in the organisation because of operations with limited capacities that govern flow. Throughput is therefore defined in this perspective as the rate of production, and does not consider sales as defined in the value perspective.

Phase 1: Constraint exploitation

The system has one immediate constraint that must be identified and exploited in order to streamline operations and improve throughput. Various basic techniques can be utilised for constraint identification, but the most effective technique is to find the operation with the longest cycle time; this is the operation with the lowest throughput.

Exploitation activities can be initiated once the constraint is identified; standardised work, visual management, and the 5-S movement provided the foundation for these activities. The constraint must be made transparent so that people know where to focus their attention. Exploitation activities must only use available resources and people in order to decrease the workload or increase the throughput of the constraint.

Decrease the workload of the constraint through the elimination of insignificant work, or work that can be performed by other operations; even if these operations are less efficient, the workload of the constraint is reduced to increase throughput. Then make sure that the input to the constraint is free of defects, and also that the output of the constraint is within conformance; quality is discussed in detail in the next perspective.

Increase the throughput of the constraint with more efficient practices. The simplest approach is to ensure that the most productive and skilled person is assigned to the constraint. Also train several people in the skills required for constraint operation to guarantee a functional constraint even when some people are absent. Furthermore, continue to execute standardised work, visual management, and the 5-S movement.

Phase 2: Process flow

Process flow is important to support the constraint and to encourage additional waste elimination activities. Operations must therefore be connected in terms of physical location and information so that work can be passed from one operation to the next without wasteful activities such as transport and delays. However, these connections lead to operations that are more dependent on each other; so when one operation shuts down, the next also shuts down. This creates a certain amount of discomfort, but it also creates a process in which people are forced to think and solve problems.

Process flow should run on an unbalanced schedule. The purpose is to ensure that other operations support the constraint with their additional capacity. This means that scheduled work must be performed as fast as possible when orders are received. Once an operation is completed the operator can clean the work area, help other team members, or execute other improvement activities. Some people attempt to balance resources to takt time, which is the minimum rate of production required to meet customer demand, but the problem with this approach is that every operation in the process can become the constraint if there is variation in the process, demand or products. Take note that resource utilisation must be optimised, and not maximised.

Phase 3: Kanban pull system

The kanban pull system is used to control the flow of work through the process based on customer consumption. This system produces what is needed, based on a signal (kanban) that connects information between operations. The purpose of the kanban pull system is to replenish buffers between operations with the same amount of work that was removed. These buffers are used to protect the process from variation and minimise overproduction, which is often used to compensate for problems that might surface when flow is created. Inventory buffers are therefore a waste, which must be removed once a predictable degree of variation is reached and the process is stable.

The PDCA cycle must be executed at least once for the perspective to be completed.

6.3.3 Quality perspective

The quality perspective deals with the management of variation in order to reduce the difference between process specifications and actual process performance. Quality is a concept that continues to develop. In the past, quality was defined as conformance to valid customer requirements. This basic definition is known as the goalpost view of quality and states that output is considered good as long as it falls within acceptable limits, called specification limits, around a desired value, called the nominal value or target value. Dr. Genichi Taguchi further refined this concept and defined quality as a predictable degree of uniformity and dependability, at low cost, suited to the market.

Phase 1: Theory of variation

Walter A. Shewart stated that variation is inherent to all processes; variation is also considered the antithesis of standardisation. However, organisations are forced to make decision based on observations and measures that are influenced by variation; therefore, variation is an important concept that must be understood, monitored, and controlled. Shewart categorised variation as either common cause or special cause.

Common cause variation is a result of the inherent design and structure of a system and should be isolated and reduced by management. Special cause variation is the result of external factors that arise because of specific circumstances, and should be detected and corrected by the people that perform the work. A process that does not exhibit special cause variation is stable; that is, it is in a predictable state of variation.

There are two fundamental types of mistakes people make in the pursuit of a stable process. The first mistake, called tampering, is to treat common cause variation as special cause variation and adjust the system; this is by far the more frequent of the two mistakes. The second mistake is to treat special cause variation as common cause variation and accept the problem. Differentiation between the types of variation is therefore important so that the appropriate actions can be taken for improvement.

Phase 2: Quality consciousness

Once the people in the organisation are aware of the theory of variation, the quality consciousness of the organisation can be determined through the manner in which the organisation deals with variation in the process. Mass inspection and control charts are used to support and advance through the different quality consciousness levels, which are defect detection, defect prevention, and continuous improvement.

Defect detection relies on mass inspection to detect and remove defectives, because defects in output are expected at this level of quality consciousness. This approach removed defectives from the process without consideration of how to avoid future problems and decrease variation; there is no additional feedback that supports the identification of improvement opportunities. The cost of inspection can be minimised with the kp rule, but the organisation must start to promote the use of control charts.

Defect prevention strives to produce predictable output within specification limits in order to produce zero defects. This is the goalpost view of quality and is supported with attribute control charts, which are used for the identification of variation between the number or proportion of defects and defectives. The problem with this approach is that people think the process is stable when zero defects are produced; however, variation is inherent even to stable processes, so improvement must be continuous.

Continuous improvement is the constant reduction of process variation, even within specification limits, to further reduce the difference between process requirements and process performance. This is the Taguchi view of quality and is supported with variable control charts, which are used for the identification of unit-to-unit variation; more information is collected with this approach. The purpose is to reduce common cause variation within stable processes in order to compensate for inherent variation.

Phase 3: Baseline measure

Once the process is stable a performance baseline is needed as a reference point to track improvement activities. Quality measures include defect rate and process yield.

Defect rate is the proportion of nonconformances that occurred. Nonconformances are characteristics that do not perform within specification limits; each characteristic provides a defect opportunity. Defect rate can be calculated in terms of defects per million opportunities, which is also used to determine the sigma level of the process.

Process yield is complementary to the defect rate and is defined as the proportion of units that perform within specification limits. This measure can be calculated in terms of first pass yield or throughput yield. First pass yield is used to establish a baseline for current performance and throughput yield is used to predict future performance.

The PDCA cycle must be executed at least once for the perspective to be completed.

6.4 Second intermission: Reflect and prepare

The purpose of this intermission is twofold. First, management must ensure that the process throughput and the process quality are aligned toward final customer defined value. Second, management must prepare the tactic trees, from the TOC thinking process, to enhance the plan phase of the PDCA cycle. Remember that the methods that are mentioned to support each perspective are discussed in the literature study.

6.4.1 Reflect on the primary process perspective

At this point management must understand the customer perception of value in order to create actual value added processes. Constraint alleviation and waste elimination activities must also be applied for the optimisation of process throughput; this can be supported with the kanban pull system. Furthermore, manage variation with control charts and set a baseline for defect rate and process yield once the process is stable.

Table 6.4: Summarised primary process perspective

Perspectives	Phases
Value	1. Value stream creation 2. Extended 5-S movement 3. Throughput accounting
Throughput	1. Constraint exploitation 2. Process flow 3. Kanban pull system
Quality	1. Theory of variation 2. Quality consciousness 3. Baseline measures

6.4.2 Prepare the tactic trees

The tactic trees can be used as an advanced thinking approach to enhance the plan phase of the PDCA cycle. These trees utilise cause-and-effect logic to understand the problems and opportunities between the interdependent components of complex systems and develop a detailed action plan in order to reach the desired future state.

The tactic trees ensure that improvement activities focus on root problems with guidance on what to change, what to change to, and how to cause the change. This approach can be applied to tangible constraints as well as intangible constraints such as policies, paradigms, and behaviours. The trees include the current reality tree, the evaporating cloud, the future reality tree, the prerequisite tree, and the transition tree.

The *current reality tree* is a logical structure which represents the current state of a process in terms of the most probable chain of cause and effect conditions that lead to the core conflicts, or problems. This tree is an effective tool to motivate the need for improvement and also to determine where to start with improvement activities when an extensive list of problems exists. All the undesirable effects are identified and traced back to their root causes, which are responsible for the current problems.

The *evaporating cloud* (conflict resolution diagram) is an analytical structure used to achieve mutual consensus in search of plausible solutions to the inherent conflicts of the core problems. This approach focuses on the development of future conditions or actions that aim to overcome the inherent assumptions that prevent the achievement of organisational objectives. The evaporating cloud can also be used when previous solutions failed or new solutions violate current policies, paradigms, or behaviours.

The *future reality tree* represents the future state of a system, which is achieved with the implementation of actions that are designed to eliminate or reduce undesirable effects. This tree also requires consideration and incorporation of negative outcome scenarios in order to further explore solutions and ensure that undesirable effects are replaced with desirable effects. The purpose is to ensure the proposed solution will in fact resolve the unwanted system conditions without the creation of new problems.

The *prerequisite tree* is used to describe the necessary condition relationships that are required for the implementation of improvement actions. This is an effective tool that can be used for the development of an implementation roadmap to overcome the obstacles that are associated with complex solutions and procedures. The purpose is to establish intermediate objectives for the allocation and coordination of resources and people in order to deal with these obstacles and improve the process as a whole.

The *transition tree* provides the final implementation plan that represents the actions required to implement the selected improvement ideas. This action plan is used to create a shared vision that communicates and rationalises improvement activities in order to move from the current state to the desired and improved future state. The transition tree is also effective for high risk situations because the negative outcomes are considered and mitigated, or avoided, to ensure successful improvement actions.

6.5 Secondary process perspective

The secondary process perspective provides an overview of the connections between the critical process aspects. These connections integrate the critical process aspects and exploit their benefits further, in synergy with each other, because these benefits cannot be exploited in isolation to optimise the system as a whole. These connections are effectiveness, agility, and efficiency. Therefore, secondary process perspective is arranged into effectiveness perspective, agility perspective, and efficiency perspective.

Effectiveness connects value and quality. This connection focuses on the successful production of a desired output and on the alignment of the process defined quality characteristics in order to create customer perceived value. The aim of the connection is to reduce the difference between customer specifications and process performance.

Agility connects value and throughput. This connection focuses on the rapid adaption of the process to changes in customer demand and the business environment. The aim of the connection is to make the process flexible through the use of a levelled production schedule, to shorten process the lead time even when variation occurs.

Efficiency connects throughput and quality. This connection focuses on the internal operations that contribute to process flow and the performance of process defined quality characteristics. The aim of the connection is to further focus improvement activities on internal constraint alleviation once the process is aligned to create value.

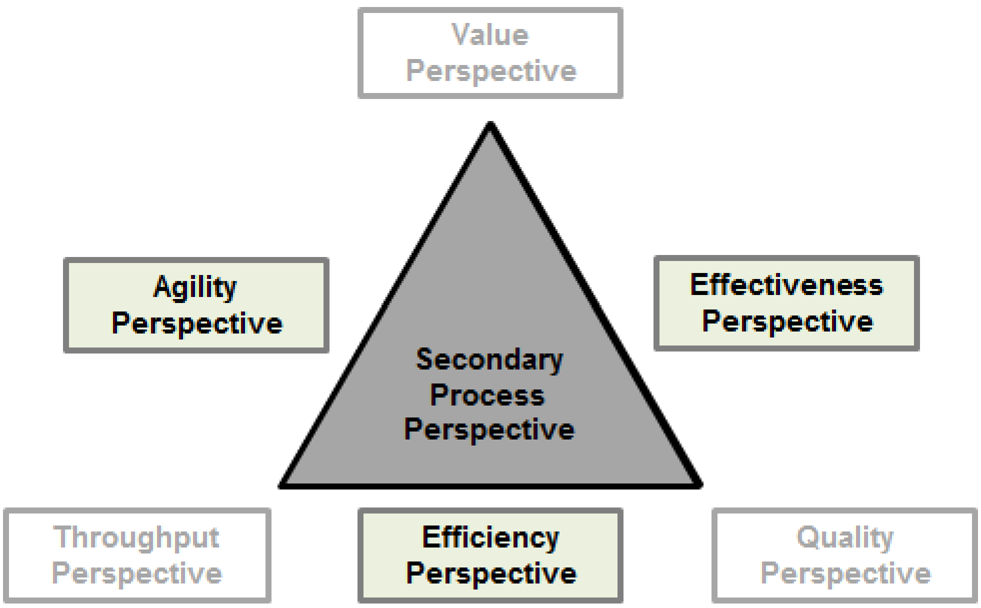


Figure 6.3: Secondary process perspective

6.5.1 Effectiveness perspective

The effectiveness perspective deals with the successful production of a desired or intended output in order to reduce the difference between customer specifications and actual process output. Therefore, the customer specifications must be understood and analysed so that improvement activities can be focused on the influential input characteristics to the process. So this perspective is executed with the end in mind.

Effectiveness is measured in terms of how successful the customer specifications are satisfied. This means that effectiveness differentiates between quality characteristics in order to produce characteristics that are significant to the final customer. However, effectiveness relies on internal operations; therefore, characteristics that influence these operations, and the customer, must be identified for improvement opportunities.

Phase 1: VOC to CTQ analysis

The first step towards improvement of process effectiveness is to transform customer specifications into quality characteristics. Customer specifications, derived from the voice of the customer, must be organised with the Kano model in order to determine the characteristics that can be used for critical to quality characteristic identification.

The voice of the customer provides the characteristics that are the main drivers for customer satisfaction. These characteristics can be defined in terms of cost, time, quality, safety, and other specific customer requirements. The voice of the customer information can be collected from customer complaints, interviews, sales, technical support, warranty claims, returns, surveys, market research, and direct observations.

The Kano model is used to analyse and organise the voice of the customer data in order to determine the effect of specific characteristics on different levels of customer requirements. The levels of requirements are defined as specifications, expectations, and delighters. This approach is crucial for detailed analysis of requirements because customers often express their requirements in a colloquial and imprecise manner.

Critical to quality characteristic identification is crucial for the selection of appropriate improvement opportunities that will have a significant and positive impact on customer satisfaction. These characteristics are derived from customer requirements and must be understood to ensure improvement focuses on the influential aspects. This requires operational definitions to drive the behaviour of people and to monitor improvements.

Phase 2: Cause and effect matrix

Once the critical to quality characteristics that influence the customer are identified, the input measures that influence the process must be identified. This is crucial in order to make a connection between customer value and process quality. The input characteristics, together with the relevant critical to quality characteristics, must be measured to create a baseline in order to monitor and control improvement activities.

The cause and effect matrix can be used to determine and select the relevant input characteristics that influence the process and the outcome to the customer. This matrix is often required when the process has multiple critical to quality characteristics; each of the significant input measure can then be identified through their correlation with the relevant quality characteristics, to determine the influence of the input characteristics.

Phase 3: Input-output correlation

The final phase is to determine the influence of the critical input characteristics on the relevant output characteristics; this influence is known as the correlation between the characteristics. Correlation is a crucial measure to ensure that improvement activities focus on the appropriate process characteristics that have a significant and positive influence on customer satisfaction. Therefore, input and output characteristics must be measured at the same time to determine how input changes affect process output.

Once the input and output data is collected a scatter plot can be constructed. Scatter plots pair the simultaneous measured values for two characteristics together in order to form x-y points that describe the correlation between the two characteristics, and also allows the identification of unusual patterns, which are the result of special causes of variation. This graphical representation of characteristics provides information on the amount of correlation, the direction of correlation, and the strength of correlation.

The *amount of correlation* describes the position of the points relative to a trend line in order to determine if the characteristics follow a predictable pattern. The *direction of correlation* describes the linear relation between the two characteristics; this can be either positive or negative if the characteristics influence one another. The *strength of correlation* describes the magnitude of the effect that one characteristic has on the other. This information can also be represented with detailed statistical calculations.

The PDCA cycle must be executed at least once for the perspective to be completed.

6.5.2 Agility perspective

The agility perspective deals with the rapid adaption of the process to changes in customer demand and the business environment. This means that the production schedule must be flexible in order to create value even when variation in customer demand occurs. The production schedule must let work flow through the process in accordance to a pull system that provides value when it is required by the customer.

Phase 1: Continuous flow

Continuous flow, also called one-piece flow, is the rapid and uninterrupted step-by-step movement of material or information through a system with minimal delays and the shortest travel distance. Continuous flow aims to increase value added activities and production throughput, but it also forces problems to the surface in order to improve the process and develop the people. Although flow is not always practical because of variation in the process and demand, it provides many opportunities for improvement.

There are several advantages to continuous flow. First, defects are easier detected and fixed in smaller batches. Second, processes are more flexible because of shorter lead times. Third, operations are pushed together to improve floor space utilisation and encourage waste elimination. Fourth, employee morale increases because of transparent operations and visible improvement. Fifth, standard procedures and an organised environment reduce the likelihood and severity of hazardous occurrences.

Phase 2: Load levelling

Level the workload over a period of time, rather than to produce output in relation to the actual fluctuation of customer demand. This is important because customers do not submit orders for specific batch sizes, even though batch production is the norm, and variation of customer demand causes overburden and unevenness. Overburden is the assignment of unreasonable stress or effort to a person, piece of equipment, or machine. Unevenness is the presence of variation that leads to unbalanced situations.

Production of smaller batches that are aligned with actual customer consumption must be considered when one-piece flow is not practical. This approach should focus on a levelled production volume and mix in order to level out the total demand on people, equipment, and suppliers. The three inputs to considered for a levelled schedule are built-to-stock, built-to-order, and the amount of buffer stock required to maintain the constraint. Note that single minute exchange of die is crucial for this to be successful.

Phase 3: Drum-buffer-rope method

The drum-buffer-rope method has two functions. First, work flow is regulated through the constraint in order to produce what is needed, when it is needed; understand that this pull system is contrast to the push system, which releases work into the process as demand is predicted or as work becomes available. Second, non-constraints are subordinated to the constraint in order to create value, even when variation is present.

The drum is the capacity constraint of the process, which provides a beat (cycle time) to which other operations can be subordinated. Subordination is important to ensure that the constraint always operate at or near full capacity, because an hour lost at the constraint is an hour lost for the total system. The drum also provides the opportunity for a visual control point that can be used to focus improvement activities and also to maintain a levelled production schedule in order to ensure consistent process output.

The buffer is used to compensate for process variation. This buffer is measured in units of time, which schedule material release; material is released into the system at fixed time intervals in order to arrive at the constraint some period of time prior to its scheduled start. A second buffer is also used between shipment and the constraint in order to create a control point for a levelled work schedule. Furthermore, when the process is unstable a protective buffer (Kanban) can be placed in front of the constraint.

The rope is a signal that is generated, when there is a pull from the customer, in order to communicate and schedule the release of work into the process at a certain time as dictated by the buffer; the kanban pull system is analogous to a series of short “ropes”. A larger buffer can therefore be used to release work into the process earlier than required in order to compensate for variation between operations. This subordinated schedule ensures flow, without the accumulation of excess inventory.

The drum-buffer-rope method is used to release material into the process, at fixed time intervals, with the amount of work that the customer requested. This creates an unbalanced production line, which allows non-constraints to ensure smooth operation of the constraint even in a system with high variation and product mixes. This method is opposite to the inventory based kanban pull system, but the kanban system is still useful when the process is unstable. However, a large kanban is considered a waste.

The PDCA cycle must be executed at least once for the perspective to be completed.

6.5.3 Efficiency perspective

The efficiency perspective deals with the successful execution of operations in the shortest possible time and at the highest appropriate level of quality. This means that the process must produce output within specification limits, with the minimum amount of resources. At this point the process must be aligned with the final customer, which is the end of the process, so this perspective is considered a means to the end. The focus of this perspective is therefore on the crucial factors that influence the constraint and the process as a whole, without direct consideration of customer specifications.

Phase 1: Constraint elevation

Constraint elevation relies on large investment in resources in order to eliminate the immediate constraint with the execution of substantive improvement activities. These activities should therefore only be executed when the primary process perspective is implemented and constraint exploitation and subordination of non-constraint did not manage to eliminate the immediate constraint. Built-in-quality and total productive maintenance is discussed in this perspective in order to support constraint elevation.

Constraint elevation activities should ensure that the constraint operates at maximum utilisation with the current resources. Only when demand is higher than the capacity at maximum utilisation, additional resources and people can be acquired to increase capacity, or some of the work can be outsourced to decrease the workload. Constraint elevation activities must continue to decrease the workload or increase throughput until the immediate constraint is eliminated. Performance data must therefore be analysed in order to determine the need for investment and its effect on the process as a whole.

Phase 2: Built-in-quality

People are part of the solution, not the problem. However, people are often blamed for problems, but problems occur because people interact with inefficient processes and poor work methods. Continuous improvement activities must therefore focus on built-in-quality and the decision to stop and fixed problem at the point of occurrence.

Built-in-quality is used for the detection and prevention of errors. This concept is also crucial for the development of a culture that fixes problems at the point of occurrence, even when production must be stopped; a stable process is therefore essential to avoid excessive stoppages. Furthermore, build-in-quality calls for extensive support structures and small batch production in order to improve the detection and prevention of errors.

Poka-yoke, which is an inherent part of built-in-quality, can be defined as a device or procedure that eliminates conditions that introduce errors into the process, or makes mistakes apparent for elimination. This simple concept is effective at locations where people are responsible for a process because it prevents human errors. Poka-yoke devices should be cost effective, part of the process, and able to provide rapid visual feedback from where the error occurred in order to initiate immediate corrective actions.

Failure mode and effect analysis can be used for the identification and prioritisation of built-in-quality opportunities. This approach focuses on the significant components that can lead to failure and the impact of failure on customer satisfaction and process performance. The three factors that must be considered are severity of the possible effect, the occurrence probability, and the detectability of possible failures. Once these factors are understood the highest prioritised failure opportunities can be eliminated.

Phase 3: Total productive maintenance

Total productive maintenance consists of three aspects that ensure continuous flow and consistent performance: (1) the prevention of breakdowns with the execution of maintenance prior to failure, (2) the simplification of maintenance activities in order to make it easier and safer, and (3) the design of machines and equipment that requires little or no maintenance. These aspects must be subordinated to the constraint and the affected people must be empowered to participate in basic maintenance activities.

Overall equipment effectiveness (OEE) can be used for the analysis and evaluation of maintenance activities. This indicator is calculated as the product of availability rate, performance rate, and quality rate. *Availability rate* is the actual amount of time that equipment is in operation versus the available time, or load time. *Performance rate* is the product of the amount of units produced and the theoretical cycle time per unit, versus the total actual production time. *Quality rate* is the total amount of units that fall within process specification limits, versus the total amount of units produced.

The kanban pull system can be used to accommodate poor equipment utilisation when operations are connected. However, realistic target values to strive toward for the three OEE factors are an availability rate that surpasses 90%, a performance rate above 95%, and a quality rate that exceeds 99%, in order to ensure at least 85% OEE.

The PDCA cycle must be executed at least once for the perspective to be completed.

6.6 Resolution: Transcend above perspective

The secondary process perspective is the first perspective that took a step back, for a higher level overview, in order to connect the individual perspectives that compose the primary process perspective. This includes the management of input and output characteristics in order to reduce the difference between customer specifications and process output. Furthermore, rapid adaptation of the process and flexible operations must be pursued. Then the process constraint must be further alleviated in order to produce output in the shortest possible time, at the highest appropriate level of quality.

Table 6.5: Summarised theory of perspective

Organisational perspective	
Philosophy	1. Constancy of purpose 2. Long-term strategic management 3. Continuous improvement culture
People	1. Pride and joy in workmanship 2. Knowledge, collaboration, and leadership 3. Empowerment
Process	1. Process orientated view 2. Appreciation of the system 3. Stable processes
Primary process perspective	
Value	1. Value stream creation 2. Extended 5-S movement 3. Throughput accounting
Throughput	1. Constraint exploitation 2. Process flow 3. Kanban pull system
Quality	1. Theory of variation 2. Quality consciousness 3. Baseline measures
Secondary process perspective	
Effectiveness	1. VOC-to-CTQ analysis 2. Cause and effect matrix 3. Input-output correlation
Agility	1. Continuous flow 2. Load levelling 3. Drum-buffer-rope method
Efficiency	1. Constraint elevation 2. Built-in-quality 3. Total productive maintenance

At this point management must understand the purpose and implementation of each perspective discussed in this roadmap. The PDCA cycle should also be an inherent part of the organisational culture in order to support and standardise improvement activities. Management must also see improvement as the optimisation of resources, and not as the maximisation of resources utilisation. When the roadmap is understood and mastered improvement activities can transcend above the individual perspectives.

Transcend above perspective means that management must take another step back for a higher level overview, as done in the secondary process perspective, in order to view process improvement as a whole. This view can be seen as performance, which is comprised of effectiveness, agility, and efficiency. The improvement of process performance must be implemented with knowledge of the organisational perspective in order to improve the organisation as a whole. This nonlinear approach relies on management to sustain improvements, exploit opportunities, and pursue perfection.

The improvements that were implemented throughput the roadmap, as well as future improvements, must be sustained. Therefore, activities that monitor and control the process must be standardised to ensure that new behaviours become routine. Other direct methods to sustain improvements include visual management, standardisation of procedures, and participation of the affected people. Furthermore, improvements must be supported and sustained with the possible alteration of policies and priorities.

Do not focus on the correction of problems in the current state; exploit opportunities to reach the future state. Management must rather focus on opportunities to eliminate the condition that lead to problems. First, understand the process as a whole, before the identification of improvement opportunities. Second, implement solutions in order to exploit these opportunities, and then implement the successful solutions in other locations with the support of organisational wide cooperation and coordination. This can be summarised as: Think global, then local, but implement local, then global.

The nature of continuous improvement means that after the successful completion of improvement activities, new opportunities must be identified. This is also important because organisations are under pressure to be flexible and adapt to changes in the current competitive business environment. The PDCA is a crucial approach that must be repeated and the methods that are inherent to the PDCA cycle will also be more beneficial when used for incremental improvements that strive to pursue perfection.

7. Validation

The entire continuous improvement roadmap discussed in Chapter 6 was developed from lean thinking, theory of constraints, and six sigma. Each of the principles and methods, except for the PDCA cycle, used in the roadmap was extracted from the three continuous improvement methodologies as discussed in the literature study.

The organisational perspective was derived and extended from the 4P principles of Lean Thinking. These are philosophy, people and partners (partners are external and therefore not part of the roadmap), problem solving (this is inherent to the roadmap), and process focus. The phases discussed within the organisational perspective are also further supported with Deming's theory of profound knowledge for management.

Each of primary process perspectives is inspired and derived from the main focus point of each of the discussed improvement methodologies; value is derived from lean thinking, throughput is derived from TOC, and quality is derived from six sigma.

The secondary process perspectives provide an overview of the direct connections between the primary process perspectives. These connections are crucial to ensure compliance, integration, and cohesion of improvement activities. The phases of the process perspectives are copied from the discussed improvement methodologies and included in the roadmap to support the intent of each phase. The main source of each process perspective and their phases are shown in Table 7.1 on the next page.

The identification of the process perspectives and their integration was introduced in the article "Enhancing project management in South African small businesses by focusing on process improvement methodologies", which was presented at the 25th conference of the South African Institute for Industrial Engineering (SAIEE). [104]

Future potential validation of the roadmap can include interviews with small business managers and actual implementation of the roadmap. The interviews can focus on the comprehension of strategic support and competence of managers to understand and utilise the technical support that is discussed within the roadmap. The next step can then be the actual implementation of the roadmap to determine the effect that successful implementation can have on the overall performance of a small business.

This roadmap also provides some opportunities for further research and case studies to evaluate each perspective for refinement and actual implementation. The roadmap can also be customised for specific industries and the implication of each perspective in different situations. Furthermore, the role of modern technology can be evaluated to determine the integration of the roadmap within enterprise information systems.

Table 7.1: Main source of each improvement phase

Primary process perspective		
Value (LT)	1. Value stream creation 2. Extended 5-S movement 3. Throughput accounting	LT LT TOC
Throughput (TOC)	1. Constraint exploitation 2. Process flow 3. Kanban pull system	TOC TOC LT
Quality (SS)	1. Theory of variation 2. Quality consciousness 3. Baseline measures	SS SS SS
Secondary process perspective		
Effectiveness (LT and SS)	1. VOC-to-CTQ analysis 2. Cause and effect matrix 3. Input-output correlation	SS SS SS
Agility (LT and TOC)	1. Continuous flow 2. Load levelling 3. Drum-buffer-rope method	LT LT TOC
Efficiency (SS and TOC)	1. Constraint elevation 2. Built-in-quality 3. Total productive maintenance	TOC LT LT
Sources: LT = Lean Thinking TOC = Theory of Constraints SS = Six Sigma		

8. Conclusion

Small, medium and micro enterprises are important contributors to the economic and socioeconomic development of South Africa. However, most enterprises struggle to become established. The high rate of failure is due to a lack of access to finance, poor managerial and technical skills, and also the competitive business environment.

The goal of this research report is to develop a systematic and proactive roadmap that provides skill constrained small business managers with basic directions toward sustainable and internal process improvement, without expensive external consultation.

Two objectives have been identified that must be completed in order to achieve the goal: strategic support and technical support. Strategic support was derived from the three improvement methodologies, based on their values and beliefs of how to approach continuous improvement. Technical support is provided with the ten step basic improvement cycle, which is based on an interpretation of the PDCA cycle, and the methods that were identified for the execution of the improvement methodologies.

Strategic and technical support is integrated into one roadmap that provides the principles, strategies, and methods required for successful and sustainable process improvement. This roadmap is called the theory of perspective, and is based on the principle that perspectives can be used to develop the perception of people toward process improvement. The values and beliefs that drive these perspectives are direct reflections of the literature, which consists of theoretical sources and case studies.

Future research can focus on the development of a continuous improvement manual with detailed instructions for the execution of each perspective. This manual can include case studies, additional methods, and detailed explanations of the principles that drive different philosophies and behaviours. Future research can also explore the two ideas, stated below, for further development of the theory of perspective.

"Do not improve the process as an external consultant; improve how people perceive the process so that improvement can become inherent to the organisational culture."

"Break down the walls of perception with knowledge of organisational and process perspectives in order to transcend above current methods of continuous improvement."

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