

# Critical evaluation of the Theory of Constraints Lean Six Sigma continuous improvement management approach

Rojanette van Tonder

13033166

Dissertation submitted in partial fulfilment of the requirements for the degree  
*Master of Engineering in Development and Management* at the  
Potchefstroom Campus of the North-West University, South Africa

Supervisor: Prof. J.H. Wichers  
May 2011

## Acknowledgements

*“I will instruct you and teach you in the way you should go; I will counsel you with my eye upon you.”*

*Psalm 32:8*

I would like to thank my Heavenly Father for guiding me throughout my life and counselling me. Thank you for your grace, for keeping an eye on me and loving me.

My most heartfelt gratitude also goes to my parents, Johann and Ronel, for all the sacrifices that you have made; thank you for all your support, love and prayers. Thank you also to my grandparents Graham and Nellie Brown for your guidance, love, support and prayers.

Thank you to Gideon Coetzee (Jnr.) for your support, love and patience.

I am grateful to Jonker Sailplanes for the opportunity to implement TLS in the organisation.

Especially, I want to extend my gratitude to Mr. Iain Baker, The Zen Pilot, for being my Lean mentor and for coaching me. Thank you for the great impact you had on Jonker Sailplanes in transforming it into a more ‘Lean organisation’.

My sincere gratitude is also extended to Mr. Gideon Coetzee, Production Manager of Jonker Sailplanes, for his mentoring and support. Thank you for the assistance in the implementation of this project.

Thank you to Mr. Danie Dahms, Financial Manger of Jonker Sailplanes, for assisting me in the financial verification of the project. And, finally, thank you to Me Carina van Zyl and Carin van Zyl for the administrative assistance.

# Table of contents

<b>Acknowledgements</b> .....	<b>ii</b>
<b>List of figures</b> .....	<b>viii</b>
<b>List of tables</b> .....	<b>x</b>
<b>List of graphs</b> .....	<b>x</b>
<b>List of abbreviations</b> .....	<b>xi</b>
<b>Glossary of terms used</b> .....	<b>xii</b>
<b>Keywords</b> .....	<b>xv</b>
<b>Executive summary</b> .....	<b>xv</b>
<b>Background</b> .....	<b>xvii</b>
• A brief history of Jonker Sailplanes .....	xvii
• The product.....	xvii
• The people .....	xxi
• Competition awards .....	xxii
• From prototyping to production.....	xxiii
• Conclusion .....	xxv
<b>Chapter 1 : Introduction</b> .....	<b>1</b>
1.1. Problem statement.....	1
1.2. Research aims and objectives.....	5
1.3. Expected deliverables.....	5
1.4. Method of investigation.....	6
<b>Chapter 2 : Literature survey</b> .....	<b>7</b>
2.1. Theory of Constraints .....	7
2.1.1. The Goal .....	7
2.1.2. Phenomena within a plant .....	8
2.1.3. Types of resources .....	12
2.1.4. Constraints.....	12
2.1.5. Drum-Buffer-Rope (DBR) .....	17
2.1.6. The next logical steps.....	27
2.1.7. Fundamental erroneous assumptions .....	29
2.1.8. A process of ongoing improvements .....	30
2.1.9. Common sense.....	31
2.2. The Toyota Lean Manufacturing System.....	32
2.2.1. What is Lean thinking? .....	32
2.2.2. Lean definitions.....	33

2.2.3.	TPS vs. the Toyota Way .....	33
2.2.4.	The Lean temple .....	33
2.2.5.	The 14 principles of the “Toyota Way” .....	36
2.2.6.	Traditional organisation vs. Lean organisation .....	77
2.2.7.	Lean myths .....	78
2.2.8.	Overall benefits of implementing Lean .....	78
2.3.	Six Sigma.....	80
2.3.1.	Introduction .....	80
2.3.2.	Basic Six Sigma concepts .....	82
2.3.3.	Six Sigma methodology (DMAIC).....	88
2.3.4.	Six Sigma belt system .....	99
2.3.5.	Why use process sigma as a metric?.....	103
2.3.6.	Six Sigma Conclusion.....	104
2.4.	Theory of Constraints Lean Six Sigma (TLS).....	105
2.4.1.	Theory of Constraints Lean Six Sigma methodology .....	105
2.4.2.	TLS case study .....	107
2.5.	Literature survey: Summary and conclusion .....	109
<b>Chapter 3 : Theory of Constraints Lean Six Sigma implementation plan for Jonker Sailplanes .....</b>		<b>111</b>
3.1.	Implementation plan for Jonker Sailplanes.....	111
3.1.1.	Step 1: Specify the organisation's long-term philosophy .....	111
3.1.2.	Step 2: Identify the constraint .....	112
3.1.3.	Step 3: Exploit the constraint.....	112
3.1.4.	Step 4: Subordinate other activities to the constraint .....	112
3.1.5.	Step 5: Elevate the constraint.....	112
3.1.6.	Step 6: Avoid negative inertia.....	112
3.1.7.	Step 7: Specify the value .....	112
3.1.8.	Step 8: Identify the value stream .....	113
3.1.9.	Step 9: Make value flow without any interruptions .....	113
3.1.10.	Step 10: Let the customer pull value from the producer.....	114
3.1.11.	Step 11: Focus on the people in the organisation and the partners outside the organisation	114
3.1.12.	Step 12: Implement with agility.....	114
3.1.13.	Step 13: Become a learning organisation .....	115
3.1.14.	Step 14: Pursue perfection .....	115
3.1.	Implementation of Six Sigma at Jonker Sailplanes .....	116
3.2.	Conclusion .....	117
<b>Chapter 4 : Implementing Theory of Constraints Lean Six Sigma (TLS) at Jonker Sailplanes .....</b>		<b>118</b>
4.1.	Specify the organisational long term philosophy .....	118

4.2.	Identify the constraint.....	118
4.3.	Exploit the constraint .....	119
4.4.	Subordinate other activities to the constraint.....	120
4.5.	Elevate the constraint .....	121
4.6.	Avoid negative inertia .....	122
4.7.	Specify the value .....	122
4.8.	Identify the value stream.....	122
4.9.	Make value flow without any interruptions.....	125
4.9.1.	Create continuous process flow to bring problems to the surface .....	125
4.9.2.	Use “pull” systems to avoid overproduction .....	125
4.9.3.	Level out the workload - Work like the tortoise, not the hare .....	127
4.9.4.	Build a culture of stopping to fix problems, in order to get quality right the first time. ....	132
4.9.5.	Standardised tasks are the foundation for continuous improvement and employee empowerment.....	132
4.9.6.	Use visual control so that no problems are hidden .....	133
4.9.7.	Use only reliable, thoroughly tested technology that serves your people and processes.....	134
4.10.	Let the customer pull value from the producer .....	135
4.11.	Focus on the people in the organisation and the partners outside the organisation.....	135
4.11.1.	Grow leaders who thoroughly understand the work, live the philosophy and teach it to others .....	136
4.11.2.	Develop exceptional people and teams who follow the company’s philosophy.....	136
4.11.3.	Respect the extended network of partners and suppliers by challenging them and helping them improve .....	137
4.12.	Implement with agility .....	137
4.13.	Become a learning organisation .....	138
4.13.1.	Go and see for yourself to thoroughly understand the situation.....	138
4.13.2.	Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly .....	138
4.13.3.	Become a learning organisation through relentless reflection and continuous improvement .	140
4.14.	Pursue perfection.....	142
4.15.	Conclusion .....	144
<b>Chapter 5 : Results and findings.....</b>		<b>145</b>
5.1.	Production tempo (throughput).....	145
5.2.	Organisational profit.....	146
5.3.	Conclusion .....	150
<b>Chapter 6 : Critical evaluation of the Theory of Constraints Lean Six Sigma methodology .....</b>		<b>151</b>
6.1.	Implementation difficulty .....	151
6.2.	Production tempo (throughput).....	153

6.3.	Organisational profit.....	153
6.4.	Critical evaluation conclusion .....	154
<b>Chapter 7 : Discussion and interpretation .....</b>		<b>155</b>
7.1.	From prototyping to production.....	155
7.2.	Implementing Lean before TOC .....	163
7.3.	Starting point of the continuous improvement project .....	165
7.4.	Identifying the constraint at Jonker Sailplanes .....	166
7.5.	Conclusion .....	166
<b>Chapter 8 : Recommendations .....</b>		<b>167</b>
8.1.	Recommendation 1 – Long-term vision.....	167
8.2.	Recommendation 2 - Implementing Six Sigma .....	167
8.3.	Recommendation 3 – Metal kitting system.....	168
8.4.	Recommendation 4 – Group Leaders .....	169
8.5.	Recommendation 5 - Leaders .....	172
8.6.	Recommendation 6 – Employee motivation.....	172
8.7.	Recommendation 7 - Suppliers .....	174
8.8.	Recommendation 8 – Visual management.....	174
8.9.	Recommendation 9 – Non-conformances.....	175
8.10.	Recommendation 10 – Teamwork.....	175
8.11.	Conclusion .....	176
<b>List of references .....</b>		<b>177</b>
<b>Appendices.....</b>		<b>181</b>
	Annexure 1: Value stream map data for Final Assembly .....	181
	Annexure 2: Six Sigma tools and techniques .....	184
•	Project charter .....	184
•	Suppliers-Inputs-Process-Outputs-customer diagram (SIPOC).....	184
•	Stakeholder analysis.....	185
•	VOC analysis .....	186
•	Affinity diagram .....	186
•	Critical-to-Quality (CTQ) tree.....	187
•	Prioritisation matrix .....	187
•	Gage repeatability and responsibility study.....	188
•	Control charts .....	189
•	Run charts .....	189
•	Histograms.....	190
•	Pareto charts .....	191

- Cause-and-defect diagram (fishbone / Ishikawa diagram)..... 192
- Regression analysis..... 192
- Scatter plots..... 192
- Design of experiments (DOE)..... 193
- Failure mode and effects analysis (FMEA)..... 193

## List of figures

Figure 0-1: JS1 in flight .....	xviii
Figure 0-2: JS1 in flight .....	xviii
Figure 0-3: The JS1 sailplane banking to the right .....	xix
Figure 0-4: The JS1, not as gracious on the ground as in the air .....	xix
Figure 0-5: JS1 instrument panel .....	xx
Figure 0-6: JS1 cockpit .....	xx
<b>Figure 0-7: Initial JS1 team right after the maiden flight of the prototype in 2006.....</b>	<b>xxi</b>
Figure 0-8: JS1 team in March 2010.....	xxi
Figure 0-9: Prototyping done in one hanger .....	xxiv
Figure 2-1: The troop analogy.....	9
Figure 2-2: Troop analogy - slowest in front .....	11
Figure 2-3: Troop analogy: Drum-Buffer-Rope .....	18
Figure 2-4: The Drum-Buffer-Rope way.....	19
Figure 2-5: DBR system - Single assembly line.....	20
Figure 2-6: DBR: multiple assembly lines .....	21
Figure 2-7: Synchronised manufacturing: the Drum-Buffer-Rope way .....	22
Figure 2-8: The time buffer.....	25
Figure 2-9: Desired planned vs actual buffer pattern.....	26
Figure 2-10: Buffer management .....	27
Figure 2-11: The Lean temple.....	34
Figure 2-12: A "4P" model of the Toyota Way .....	36
Figure 2-13: Batch production vs one-piece flow.....	39
Figure 2-14: Sea of inventory.....	43
Figure 2-15: Lower levels of inventory .....	43
Figure 2-16: A Toyota leader's view of the TPS .....	54
Figure 2-17: Toyota leadership model .....	55
Figure 2-18: Typical Toyota organisation.....	59
Figure 2-19: Supplier chain need hierarchy (modelled after Maslow's need hierarchy).....	65
Figure 2-20: Alternative Toyota decision-making methods.....	69
Figure 2-21: Plan-Do-Check-Act in the proposal process .....	70
Figure 2-22: 5-why investigation questions.....	73
Figure 2-23: Policy deployment process ( <i>hoshin kanri</i> ).....	76
Figure 2-24: Bell-shaped (normal) curve .....	84
Figure 2-25: Percentages of values contained within one, two and three standard deviations.....	85
Figure 2-26: Six Sigma quality process .....	86

Figure 2-27: The 1.5 $\sigma$ shift.....	86
Figure 2-28: DMAIC methodology (continue on next page) .....	89
Figure 2-29: DMAIC methodology (continue from previous page) .....	90
Figure 2-30: Six Sigma organisations .....	99
Figure 2-31: Example - Six Sigma Leader job description.....	100
Figure 2-32: Example - Master Black Belt job description .....	101
Figure 2-33: Example - Black belt job description.....	102
Figure 2-34: The functions of each role during Six Sigma.....	103
Figure 2-35: Percentage of contribution to savings realised.....	109
Figure 3-1: Transition from Lean to Six Sigma .....	117
Figure 4-1: Partial value stream map for Final Assembly .....	123
Figure 7-1: Manufacturing done in one hanger.....	156
Figure 7-2: Jonker Sailplanes production line.....	157
Figure 7-3: Production line developing - Small Composite cell .....	158
Figure 7-4: Closing the wing moulds.....	159
Figure 7-5: Closing the fuselage moulds .....	159
Figure 7-6: Production line developing – Wing Pre-close Assembly cell.....	160
Figure 7-7: Production line developing - Jonker Sailplanes spray booth.....	161
Figure 7-8: Production line developing - Final Assembly cell .....	162
Figure 7-9: Transition in Jonker Sailplanes.....	163
Figure 0-1: Example of a SIPOC diagram .....	185
Figure 0-2: Stakeholder chart.....	186
Figure 0-3: Example of a CTQ tree.....	187
Figure 0-4: Prioritisation matrix example .....	188
Figure 0-5: Control chart example .....	189
Figure 0-6: Run chart example.....	190
Figure 0-7: Example of a histogram.....	190
Figure 0-8: Pareto chart example .....	191
Figure 0-9: Cause-and-effect diagram (fishbone diagram).....	192
Figure 0-10: Example of a scatter plot.....	193

## List of tables

Table 0-1: JS1 specifications .....	xvii
Table 2-1: The differences between traditional and Lean organisations .....	77
Table 2-2: Myths versus reality of TPS .....	78
Table 2-3: Sigma scale table.....	87
Table 2-4: Process sigma quality scale .....	104
Table 4-1: Root causes for frequent changing between value-adding activities and non-value adding activities.....	123
Table 8-1: Roles and responsibilities at Toyota vs. Jonker Sailplanes.....	171

## List of graphs

Graph 3-1: Jonker Sailplanes throughput .....	116
Graph 5-1: Jonker Sailplanes throughput .....	145
Graph 5-2: Total income from aircraft sales.....	146
Graph 5-3: Total operating expenses .....	147
Graph 5-4: Total salaries.....	147
Graph 5-5: Income per aircraft.....	148
Graph 5-6: Operating expenses per aircraft .....	149
Graph 5-7: Salaries paid per aircraft.....	149
Graph 8-1: Jonker Sailplanes throughput forecast .....	167

## List of abbreviations

CCR	-	Capacity constraint resource
CTQ	-	Critical-to-quality
DBR	-	Drum-Buffer-Rope
DMAIC	-	Define Measure Analyse Improve Control
DPMO	-	Defects per million opportunities
JIT	-	Just in time
JS	-	Jonker Sailplanes
OTS	-	Off-the-shelve
ppb	-	Part per billion
ppm	-	Part per million
TLS	-	Theory of Constraints Lean Six Sigma
TOC	-	Theory Of Constraints
TPS	-	Toyota Production System
WIP	-	Work in progress

## Glossary of terms used

- Andon* - A signalling system that indicates where help is needed in order to solve a quality problem; A means of stopping the production line when a worker sees that something is out of standard.
- Defect - Any event that does not meet a customer's specification.
- Genchi genbutsu* - Going to the place to see the actual situation with a view to increase understanding.
- Heijunka* - Levelling of production by both volume and product mix.
- Hansei* - Reflection on a situation and the contribution that the individual has made.
- Hoshini kanri* - A measurement that tracks progress towards stretched improvement goals.
- Jidoka* - Autonomation (equipment endowed with human intelligence to stop itself when it experiences a problem).
- Jishuken* - Voluntary study groups used to assist other organisations to become Lean organisation.
- Kaizen* - The *kaizen* philosophy is drawn from the Japanese word 'kai' which means "continuous" and 'zen' meaning "improvement" or "wisdom". The management philosophy, therefore, is defined as making "continuous improvement"—slow, incremental but constant (World class manufacturing).
- Kanban system* - An organised system of inventory buffers.
- Muda* - Non-value adding activities that appear in the eight forms of waste.
- Muri* - Overburdening people and equipment; pushing them over their natural limits.

<i>Mura</i>	- Unevenness in production levels. Sometimes there is more work than the people or machines can handle, and at other times there is a lack of work.
<i>Nemawashi</i>	- To discuss problems and possible solutions with all the parties effected, to collect their thoughts and to reach an agreement on what to do. Making decisions slowly by consensus, thoroughly considering all options; implement rapidly.
Non-value adding activities	- Unavoidable processes with current technology/methods. Any work carried out that does not increase the product value.
Process	- Any series of operations performed to bring about a result.
<i>Seiri</i>	- Sort – Sort through items and only keep what is necessary while disposing of the rest.
<i>Seiso</i>	- Straighten (orderliness) – A place for everything and everything in its place.
<i>Seiketsu</i>	- Shine (cleanliness) – The cleaning process often acts as a form of inspection that exposes abnormal and pre-failure conditions that could hurt quality or cause a machine failure.
<i>Shitsuke</i>	- Standardise (create rules) – Develop systems and procedures to maintain and monitor the first three S's.
<i>Seiton</i>	- Sustain (self-discipline) – Maintaining a stabilised workplace as an ongoing process of continuous improvement.
Specification	The limit or set of limits placed on a key, measurable characteristic of importance to the customer, called a Critical-to-Quality requirement.
Value-adding activities	- Any process that changes the nature, shape or characteristics of the product, in line with customer requirements.

- Value stream map - A diagram of all actions (both value-added and non-value added required to bring a product from raw material to the customer.
- Variation - The sum total of all the minuscule changes that occur every time a process is performed and all of the not-so-minuscule changes that occur on occasion.
- Waste - All meaningless, non-essential activities that do not add value to the product that can be eliminated immediately.

## Keywords

Lean, Theory Of Constraints (TOC), Six Sigma, production optimisation, aircraft manufacturing, continuous improvement, *kaizen*, Theory of Constraints Lean Six Sigma (TLS).

## Executive summary

Three methodologies are associated with production optimisation, namely, Theory of Constraints (TOC), Lean and Six Sigma – and each boasts with a number of success stories. This dissertation addresses the possibility of implementing all three these methodologies in a specific sequence at an organisation and also sets out to determine the impact of this implementation.

A literature survey was conducted on all three stand-alone methodologies as well as on the combined methodology, which is called the *Theory of Constrains Lean Six Sigma* (TLS). TLS literature suggests that TOC should be implemented first with a view to identify the constraint in an organisation. Lean implementation should follow in order to eliminate any waste in the organisation. Lastly, Six Sigma should be implemented to optimise the process variability.

TOC literature explains that *The Goal* of any organisation is to make money. All other objectives are only the means of achieving *The Goal*. The literature further indicates that the constraint in any organisation determines the drumbeat, and that this constraint should be managed by means of the Drum-Buffer-Rope methodology.

Lean literature points towards 14 Management Principles by means of which an organisation should be managed in order to become a Lean organisation, while Six Sigma literature is concerned with the DMAIC (Define-Measure-Analyse-Improve-Control) methodology used for improvement projects and the belt system that is used to manage these improvement projects.

Jonker Sailplanes, a sailplanes manufacturer in Potchefstroom, South Africa, was used as a case study for the implementation of TLS. A description is given of the processes and procedures that were followed before and after the implementation of TLS.

The TLS methodology had to be adapted in order to meet the specific needs of Jonker Sailplanes into an adapted 14-step TLS implementation plan. After implementing TOC and Lean at Jonker Sailplanes, it was found that the organisation was not ready for the transition from Lean projects to Six Sigma projects. The implementation of Six Sigma was therefore referred for future research.

One of the most significant findings of the current study was the very positive impact that the implementation of TLS had on the organisation: the production tempo (throughput) of the organisation has increased while the operating expenses per aircraft have decreased. This confirms that the profit per aircraft has increased. A critical evaluation of the implementation of the TLS methodology can therefore maintain that the implementation of TLS at Jonker Sailplanes was a success since the production tempo (throughput) and the organisational profit were increased and the implementation of the methodology was done with relative ease.

In terms of interpreting results it was also necessary to set out how Jonker Sailplanes proceeded from a prototyping environment to a production setup, and how specifically identifying the constraint helped to achieve this transition. Furthermore, is it argued that when Lean is implemented before TOC, this could move the organisation away from *The Goal*, which is to make money. The interpretation of findings suggests that the procedure followed at Jonker Sailplanes was the most appropriate one.

Finally, recommendations are made for future studies in terms of how to further improve the impact of the TLS implementation at Jonker Sailplanes.

## Background

- ***A brief history of Jonker Sailplanes***

The JS1 project started in 1999. The objective was to design and manufacture the best performing sailplane in its class together with superb handling, faultless workmanship, outstanding safety and surprising affordability. During 2006, the manufacturing of the JS1 prototype started at the manufacturing facility that is situated at the Potchefstroom airfield.

- ***The product***

The JS1 sailplane is a modern high-performance aircraft with an 18m wingspan. It is designed to use the energy of the sun in the form of rising air currents, and to soar for hundreds of kilometres at speeds of up to 270 km/h without landing.

The aircraft is capable of flying slowly and climbing well in the upwards currents and then, when reaching the clouds, it transforms into a racing machine capable of performing exceptionally at high speeds. These seemingly contradicting characteristics were innovatively achieved by the design engineers of the JS1 sailplane (see Figure 0-1 through to Figure 0-4).

The specifications of the JS1 sailplane are given in Table 0-1.

**Table 0-1: JS1 specifications**

Wing span	18.0m	59.1ft
Wing area	11.2 m <sup>2</sup>	121.1ft <sup>2</sup>
Wing loading (max)	53.3kg/m <sup>2</sup>	10.9lbs/ft <sup>2</sup>
Wing loading (min)	31.2kg/m <sup>2</sup>	6.4lbs/ft <sup>2</sup>
Max all ip weight (AUW)	600kg	1323lbs
Max speed (Vne)	290km/h	157kts
Manoeuvring speed (Vb)	198km/h	107kts
Max glide ratio (L/D)	53:1	



Figure 0-1: JS1 in flight



Figure 0-2: JS1 in flight



Figure 0-3: The JS1 sailplane banking to the right



Figure 0-4: The JS1, not as gracious on the ground as in the air

It is not only the exterior of the JS1 that is of superb quality. The cockpit area is also finished to exceptional standards. Furthermore, the cockpit area has been ergonomically designed for the utmost pilot comfort. Figure 0-5 shows an example of a JS1 instrument panel and Figure 0-6 shows the interior of the JS1 cockpit.



Figure 0-5: JS1 instrument panel



Figure 0-6: JS1 cockpit

- ***The people***

The manufacturing of the JS1 prototype started in 2006. Figure 0-7 shows the initial team responsible for the manufacturing of the JS1 prototype and for sending it on its maiden flight at the end of 2006. Since then, the employee numbers has grown close to 50. Figure 0-8 show the JS1 team that sent ten aircraft of to the 2010 World Gliding Championships in Hungary.



Figure 0-7: Initial JS1 team right after the maiden flight of the prototype in 2006



Figure 0-8: JS1 team in March 2010

- ***Competition awards***

The JS1 frequently features at competitions and has made its mark, locally as well as internationally. A few of the competition results of the JS1 are as follows:

**2007 Gauteng Regionals, Orient, South Africa**

- 4<sup>th</sup> place

**2007 Northwest Regionals, South Africa**

- 4th place

**2006-7 South African Nationals, Bloemfontein**

- 1st place

**2008 US 18m Class, Region 4 North, Fairfield PA**

- 1st place

**2008 Gauteng Regionals, Orient, South Africa**

- 3rd place

**2008 US 18m Class Nationals, Mifflin PA**

- 1st place

**2008 Free State Regionals, Welkom, South Africa**

- 2nd place

**2008 South African Nationals, Bloemfontein**

- 1st place
- 4th place

**2008-9 South African Nationals, Welkom**

- 1st place
- 3rd place
- 8th place

**2009 UK 18m Class Nationals, Husbands Bosworth**

- 1st place

**2009 US 18m Class Nationals, Ephrata WA**

- 3rd place

**2009-10 South African Nationals, Welkom**

- 1st place
- 3rd place
- 4th place
- 5th place
- 6th place

Finally, the JS1 achieved a second place in the World Gliding Championships 2010 in Hungary, Europe.

- ***From prototyping to production***

Initially, the manufacturing of the entire aircraft was completed in one hanger. This one hanger had to accommodate two 8m fuselage skin moulds (left and right), four 9m wing skin moulds (top left, top right, bottom left and bottom right), eight flapperon moulds, rudder moulds, tailplane moulds as well as all the other small composite moulds (see Figure 0-9).



**Figure 0-9: Prototyping done in one hanger**

Being a relatively new production organisation, the focus of Jonker Sailplanes initially had to be on prototyping. During these initial stages of the organisation's existence, everyone focused on one aircraft at a time. When this aircraft left the factory, everyone started on the next aircraft.

After the first few aircraft have been completed, the organisation's focus had to shift from prototyping to production where a production line set-up was required in which the work could flow from one production stage to the next.

- ***Conclusion***

Considering the history of the organisation as briefly set out above, the success of the product and the number of employees depending on Jonker Sailplanes for their income, it is apparent that the organisation needs a continuous improvement management plan in order to ensure their survival and success into the future.

Consequently, Chapter 1 elaborates further on the problem statement and the proposed research objectives in terms of improving Jonker Sailplanes' production environment.

## Chapter 1 : Introduction

This chapter presents the purpose of the research by means of setting and elaborating on the problem statement. The aims and objectives of the research are stated together with the deliverables that need to be achieved. The method of investigation that will follow in order to achieve these objectives is also stated.

### **1.1. Problem statement**

“Industrial manufacturing is witnessing an intensification of the race for the market-dominance: the life-cycle of products are shortening; zero-defects is becoming the goal of quality; new machine technology are being introduced each year and systems to control production replace each other at an unprecedented rate” (Goldratt & Fox, 1986:144). Given this reality, it can be assumed that it has become increasingly difficult to steer a company in a course that yields profits year after year. Companies must be so lean that they should waste nothing, but be agile enough to change course as customers change their demands (Jordan & Michel, 2001:1).

At one point in time, the equation for profit was as follows:

$$\text{Cost} + \text{Profit} = \text{Price}$$

In order to calculate the ‘price’, one simply added ‘cost’ to one’s desired ‘profit’.

However, this equation has changed and today it can be said to as follows:

$$\text{Price} - \text{Cost} = \text{Profit}$$

The equation has changed because the marketplace of today seems to be increasingly crowded, faster-changing and more fiercely competitive. The drastic increase in competition, together with globalisation gives buyers more choices than before. The time of ‘brand loyalty’ and simple selling has long since passed. Today, the company with the best product (and the best price) wins.

As a result, the marketplace forces a ‘price cap’ – an upper limit buyers are willing to pay for a particular product. This suggests that the best way to increase ‘profit’ is to decrease the manufacturing cost (Lean Plus, 2009).

Attempting to decrease cost, is no longer a question of surviving a cycle of good times and bad: “We can no longer use the conventional approach of cutting expenses and firing people in the bad times. We must find a way to continually improve, in good times and bad. We must choose to be in the competitive edge race” (Goldratt & Fox, 1986:14).

Furthermore, those companies unable to continually improve are falling behind, since success in this environment requires more than a one-time improvement. Each improvement does buy some time, but *The Race*<sup>1</sup> in the market continuous and relentlessly causes the slope of the curve to grow steeper and the time bought by one improvement becomes concomitantly shorter. Therefore, something far greater than a few sporadic improvements is needed. The only way to secure and improve a company’s competitive position in *The Race* is to institute a process of ongoing improvement (Goldratt & Fox, 1986:144).

According to Goldratt and Fox (1986:144), the following would be required from such a process:

- One should clearly identify at any moment the area where an improvement will yield the maximum global impact;
- The process must enable an organisation to achieve the maximum gain from such a improvement;
- Furthermore, the process should identify the area where the next improvement is needed; and
- Finally, the process should quantify the risk of the impact

When studying the success of Toyota motor vehicle manufacturers, it would seem as if they have a recipe for success: “In factories around the globe, Toyota consistently raises the bar for manufacturing, product development and process excellence. The result is an amazing business success story: steadily taking market share from price-cutting competitors, earning far more profit than any other automaker, and winning the praise of business leaders worldwide” (Liker, 2004:1).

When comparing motor vehicle manufacturing to aircraft manufacturing, there is one significant difference: Aircraft manufacturing requires the assembly of a relatively small number of large, very complicated parts whereas motor vehicle manufacturing requires mass-production of a far larger scale. (Jordan & Michel, 2001:18).

---

<sup>1</sup> *The Race* mentioned throughout this research refers to *The Race* according to Goldratt’s Theory of Constraints (Goldratt & Fox, 1986:14)

More specifically, the manufacturing of sailplanes involves the assembly of a relatively small number of high-precision metal parts and hand-manufactured composite parts. At Jonker Sailplanes, it has come to light that different factors cause delays in the manufacturing process. These delays give rise to the company often delivering their products after the agreed upon time. In those cases where products are indeed delivered on time, large amounts of overtime and extra energy are usually required.

The sailplane manufacturing process at Jonker Sailplanes therefore needs to be optimised.

Three different methodologies exist that can be used in order to optimise production by means of three different approaches:

- The Theory of Constraints (TOC) methodology can be followed to identify and exploit constraints within an organisation;
- Lean manufacturing principles can be applied to eliminate the waste within processes; or
- The Six Sigma approach can be followed to pursue perfection by optimising the process variability and errors that may occur.

The question that arises in the current study is how these three methodologies can be combined in order for an organisation to gain the benefits of all three methodologies, but by ultimately following only one combined methodology.

In 2003, Dr. Reza M. Pirasteh introduced a process called TLS (TOC Lean Six Sigma). He started to experiment with TLS in 1996 in order to find the optimal sequence in which to apply the three different methodologies. He has documented and defined his research through the TLSTM methodology.

The process of TLS utilises the Theory of Constraints (TOC), Lean and Six Sigma principles in a special sequence which is claimed to deliver higher results than would be the case if each one of the continuous improvement methodologies were used individually (Pirasteh & Farah, 2006:1).

Pirasteh and Farah (2006:1) explain the TLS process as follows:

1. TOC is applied to focus on what needs to be fixed;
2. Lean is applied in order to know how to fix it; and
3. Six Sigma is applied to keep the process optimised.

By applying the TLS methodology, the sailplanes manufacturer will benefit by becoming more trustworthy as a supplier. Also the production tempo will increase and the operating expenses will decrease, which will lead to an increase in profit.

Therefore, the problem to be researched and resolved is to determine how to make improvements in Jonker Sailplanes and in which production cell to implement these improvements, in order for these improvements to have the largest impact on the organisation as a whole. Furthermore, the effect of implementing all three methodologies in the sequence that is proposed by Pirasteh will be evaluated and commented on.

## **1.2. Research aims and objectives**

The aim of the research is to follow Pirasteh's proposed TLS methodology in order to

1. Investigate the general implementation difficulties of the methodology; and to
2. Validate its effectiveness with respect to
  - 2.1. Increased production tempo (throughput of the organisation); and
  - 2.2. Increased profit by decreasing operational expenses

The proposed objectives of the research will be the following:

1. To implement the TLS process which consists out of the following methodologies:
  - Applying the TOC process in order to determine the constraints in the organisation and to establish where improvements will have the largest impact on the organisation;
  - Implementing Lean principles in order to eliminate waste and to establish a culture of continuous improvement; and
  - Applying Six Sigma in order to optimise variability and error.
2. To critically evaluate and comment on the TLS methodology.

## **1.3. Expected deliverables**

The expected deliverables of the research are the following:

1. The documented TLS **implementation plan** that was followed at Jonker Sailplanes for the manufacturing of sailplanes;
2. The documented **impact** of implementing TLS at Jonker Sailplanes and
3. A **critical evaluation** of the TLS process in terms of
  - 3.1. Implementation difficulty
  - 3.2. The production tempo
  - 3.3. Organisational profit
4. A list of **recommendations** aimed at enhancing the production throughput of Jonker Sailplanes and also directed towards increasing the profitability of the organisation.

## **1.4. Method of investigation**

The method of investigation for this research will be divided into the following four sections:

### **A. Overview: Investigating Jonker Sailplanes**

An investigation will be conducted into the background of Jonker Sailplanes as well as the current culture of the organisation. The processes and procedures that are followed by the organisation will be studied and evaluated.

### **B. Analysis of literature and information sources**

Specialised knowledge of the following fields will be needed to complete the research:

1. The Toyota Lean manufacturing system;
2. The Theory of Constraints;
3. Six Sigma; and
4. TLS.

A survey of literature dealing with the above-mentioned fields will be conducted.

### **C. Implementation of the TLS methodology**

Pirasteh's TLS methodology will be implemented according the literature study that was conducted.

### **D. Critical evaluation of the TLS methodology**

A critical evaluation will be conducted regarding the effectiveness of the TLS process on the manufacturing of sailplanes.

## Chapter 2 : Literature survey

In this chapter an overview of all three different methodologies according to which this research was conducted, namely:

- Theory of constraints
- Lean
- Six Sigma

This chapter also explains the Theory of Constraints Lean Six Sigma (TLS) methodology which is a combination of the three abovementioned methodologies.

### **2.1. Theory of Constraints**

#### **2.1.1. The Goal**

According to Eli Goldratt and Cox (1992:41) all companies have one and only one goal. It is not to be productive or to sell products of good quality. It is not to have good customer relations and it not to provide jobs. The one and only goal of all companies, the reason for their establishment and their existence is therefore singularly to make money. All the other factors mentioned above are simply the means of achieving *The Goal*<sup>2</sup>. Making money is what *The Race* is all about.

However, this definition of *The Goal* is very generic and only addresses issues at a high level. The challenge is to take *The Goal* to the shop floor, to make it practical and implement it on a daily basis. In order to achieve this, one needs specific measurements by means of which all activities in the organisation can be measured. These measurements will have to be utilised in order to determine if any single action performed in the organisation is either a productive action or a non-productive activity.

By definition, a productive activity is an activity that helps the organisation to move towards *The Goal*. A non-productive activity is an activity that moves the organisation away from *The Goal* (Goldratt & Cox, 1992:41).

---

<sup>2</sup> *The Goal* mentioned throughout this research refers to *The Goal* of any organisation according to Goldratt's Theory of Constraints (Goldratt and Cox, 1992:41).

According to Goldratt and Cox (1992:59) the measurements by means of which one can measure all activities within an organisation are the following *operational measurements*:

- **Throughput** - The rate at which the system generates money through sales;
- **Inventory** - All the money that the system has invested in things to sell; and
- **Operational expenses** - All the money the system spends in order to turn inventory into thought put.

The bottom line of the three operational measurements is as follows:

- **Operational expenses** – Money going out of the organisation;
- **Inventory** – Money stuck in the organisation; and
- **Throughput** – Money coming into the organisation.

In order to achieve *The Goal* (making money), all three these measurements need to be improved simultaneously:

- Operational expenses need to be decreased;
- Inventory also needs to be decreased; and
- Throughput needs to be increased.

This can be explained thus: “According to these measurements, the definition of *The Goal* of an organisation is to increase through-put while simultaneously decreasing inventory and operational expenses” (Goldrat & Cox, 1992:66).

### 2.1.2. Phenomena within a plant

Within every organisation there are two phenomena’s occurring from time to time (Goldratt & Cox, 1992:98)

- **Dependant events** – An event or series of events must take place before another event can take place. The subsequent event depends on the ones prior to it.
- **Statistical fluctuations** – Information that varies all the time. These are events that cannot be predicted. They comprise of factors that are critical for running a plant successfully and cannot be determined precisely.

In order to explain the combination of these two phenomena, Goldratt uses the analogy of a troop of soldiers that are marching in a line behind each other.

As the march starts off the soldiers are right behind each other following step by step. However, as they continue on the path, gaps start to appear between the soldiers. This happens because the ability of the soldiers to walk at the same pace as the leader is not the same. Some of the soldiers are not able to keep up the pace and therefore fall behind. On the other hand, some of the soldiers are able to walk faster than the leader, but they are blocked by a slower soldier in front of him (Figure 2-1)

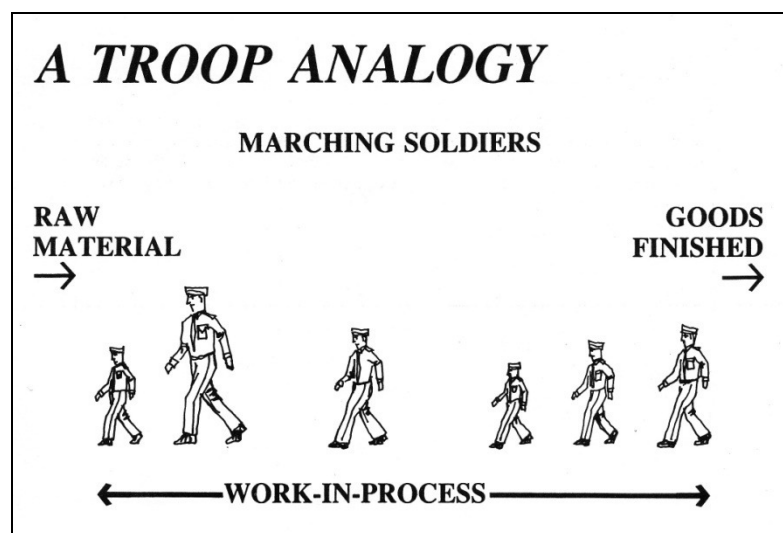


Figure 2-1: The troop analogy  
Goldratt & Fox (1986: 73)

The parallelisms between the soldiers and a production line are as follows

- **The first soldier** – The start of the production line

He represents for example the release of raw materials

- **The length of the line** – Inventory within the organisation

The longer the line of soldiers is spread out, the more inventory exists within the organisation

- **The last soldier** – Throughput

The last soldier determines the throughput and ultimately the number of sales

- **The line of soldiers** – A set of dependant events

Each soldier is dependent on what happened in front of him

- **Energy to walk** – Operational expense

By using their energy, they are able to move forward which will turn inventory into throughput

It is a truism that in this model that some soldiers walk fast and some walk slow relative to each other. One would think that the statistical fluctuation will average out throughout the day. However, this is not the case.

The *last* soldier determines the rate of throughput, but he is influenced by the fluctuating rates of the others. If a gap appears in the line and the soldier behind the gap wants to close the gap, he has to burn more energy (operational expenses) in order to do so. If it was decided that all the gaps should be closed at once, the second soldier only has to catch up his own gap, but the further back a soldier is in the line the more he has to catch up, because the slowness of each soldier in front of him has accumulated and is being passed down the line. The soldier at the back needs to make up for the accumulative slowness of all the soldiers in front of him. Therefore the soldier at the back needs to walk much faster than the soldier in front in order to keep the line short. It therefore follows that the soldier at the back would have to burn the most energy to catch up. It is apparent that the position in the line determines how much one has to catch up. Therefore, fluctuations do not average out, instead it accumulates. This means that the negative situations in a production line do not average out; it rather accumulates and is passed on down the line.

In this way slower than average production rates accumulate and work their way to the back of the production line causing this resource to slow down. Relative to the inventory, the throughput of the entire system goes down while the operational expenses (carrying cost) go up.

However, there are limits on each resource to perform faster:

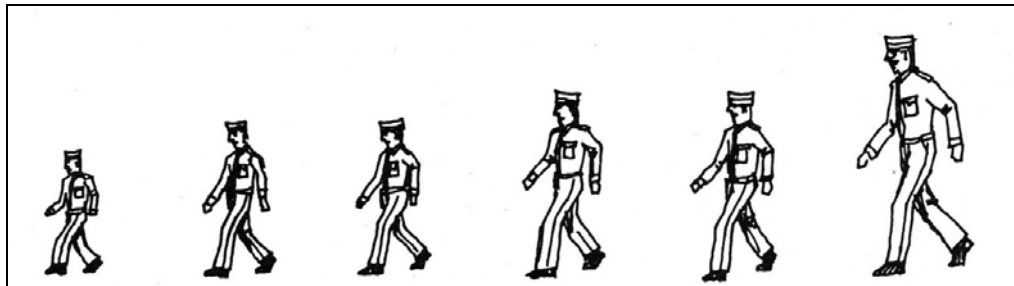
- Each resource's own capacity; and
- The capacity of the resource in front of him.

There are, however no limits on performing slower.

Goldratt and Cox (1992:72) continue to explain that when the soldiers are arranged from fastest to slowest, i.e. the fastest soldier in front of the line and the slowest soldier at the back, each soldier

will be slower than the one in front of him. This will work well for each individual, because no one is limited by the soldier in front of him, but the gaps will widen and the line will become longer.

As mentioned previously, the resources at the back need a larger capacity in order to keep the line as short as possible. Therefore, if one were to arrange the soldiers from slowest to fastest, i.e. the slowest soldier in the front and the fastest at the back, no gaps will appear. Each soldier has a slightly larger capacity than the one in front of him and is therefore able to keep up. Even when one of the soldiers has to stop to adjust his straps, for example, the rest are able to catch up and close the gap. No accumulative slowness appears and no one is out of breath because they were walking at a pace slower than their capacity (Figure 2-2).



**Figure 2-2: Troop analogy - slowest in front**  
Goldratt & Fox (1986:75)

In both cases set out above the throughput is determined by the slowest soldier. In the last case, the only way to improve the throughput is to help the soldier in front. Helping the resource with the lowest capacity will allow the rest of the resources to be able to follow automatically. Furthermore, taking the load off the front soldier and distributing it to the other soldiers will result in giving the heaviest load to the soldiers with the largest capacity.

However, it is not always possible to arrange the resources according to their capacity in a production line. The resources could be machines that have to perform task in a particular sequence (dependant events) and can therefore not be moved into a different sequence.

### 2.1.3. Types of resources

With the troop analogy in mind it is clear that there are two types of resources in a plant (Goldratt & Cox, 1992:137):

- Bottleneck resources (constraints) – Their capacity is equal to or less than the demand placed on it. They are the resources that determine the flow and ultimately the throughput of the organisation.
- Non-bottleneck resources (non-constraints) – Their capacity is greater than the demand placed on it.

According to Goldratt and Cox (1992:138), the first rule is not to balance capacity with demand, but rather to balance the flow of the product through the plant with the demand of the market. It follows that one should make the flow through the constraints equal to the demand of the market and the rest of the resources will be able to follow.

Goldratt and Cox (1992:140) explain that constraints are neither good nor bad, they are a reality. So where they exist, the flow through them should be controlled.

### 2.1.4. Constraints

In order to identify the constraint the following procedure can be followed (Goldratt & Cox, 1992:139):

1. Know the market demand;
2. Determine the capacity of each resource; and
3. Examine those resources where the capacity is less than the market demand.

A constraint can also be identified by a huge heap of inventory in front of it. The analogy of this situation is the gap in front of the slower soldier in the middle of the line.

If the flow and the throughput are determined by the constraints, the non-constraints will have reserved capacity. This is determined mathematically as follows:

$$\text{Reserved capacity} = \text{available hours} - \text{actual run time}$$

### 2.1.4.1. The effect of constraints on the organisation

According to Goldratt and Cox (1992:151), it is fairly easy to increase the capacity of the organisation; one should simply increase the capacity of the constraints. Their capacity should be made more equal to the market demand.

Since the constraints determine the throughput of the organisation, Goldratt and Cox (1992:153) explain that the cost of a constraint must be seen as the total of the entire operating cost of the organisation. It follows that the cost of an hour lost at a constraint is equal to the operating cost of the entire organisation for an hour.

Similarly, the cost of inventory piling up in front of a constraint is equal to the cost of the sales that cannot be made due to the holdup at the constraint. If one part is preventing an assembly from happening and this is preventing a sale from happening, the cost of that one part at the constraint is equal to that entire sale that is not made.

Hours lost at a constraint are hours lost to the entire plant and these hours can never be recovered. Therefore constraints should be controlled with precision.

Every time a constraint finishes a part, it is possible to ship a finished product. Only then is a sale possible. The cost of a sale is calculated by the following formula

$$\text{Cost of a sale} = \frac{\text{Total expense of the system}}{\text{Total hours the bottleneck produces a product}}$$

### 2.1.4.2. Optimising constraints

Constraints cannot always be eliminated, and they should therefore be optimised. The constraints' capacity therefore needs to be increased. Also, they need to be made more productive. According to Goldratt and Cox (1992:158) the following guidelines can be followed:

1. Ensure constraints' time is not wasted by:
  - Eliminating idle time;
  - Preventing the processing of parts that are already defective or will become defective;
  - Not working on parts that are not needed immediately (anything that is not in the current demand);
  - Not building inventory that will not increase throughput. When excess inventory is build that will only be sold later on, present money is exchanged for future money. The cash flow will possibly not sustain this; and
  - Ensure that the constraint is working at full capacity.
  
2. Take some load off constraints and give it to non-constraints by:
  - Ensuring that all the parts really have to be processed by the constraint. By eliminating some parts from the constraint, they will gain capacity; and
  - Allocating these parts to other non-constraints.
  
3. Use quality control of constraint parts differently by:
  - Putting inspection of parts in front of the constraint. If a part gets scrapped, only a scrapped part is lost. On the other hand, if a part is lost after the constraint, time is lost that cannot be recovered.
  - Preventing sub-standard quality after the constraint by ensuring good process control on parts after these has passed through a constraint, so that these parts do not get defective.
  
4. Prioritise the system by:
  - Ensuring that parts that are on their way to the constraints get first priority at the other resources. This will help to ensure that constraints do not wait for parts and idle.
  
5. Reallocate resources by:
  - Moving people from non-constraints to constraints, because they have excess capacity.

### 2.1.4.3. The Linear relationship between constraints and non-constraints

After the constraints have been addressed, some parts may still cause problems. Some parts' quantity will increase in front of the constraints or at the assembly. It will therefore seem as if more constraints have appeared, but this is not necessarily the case.

According to Goldratt and Cox (1992:160) the first step towards solving this situation is to identify those parts that are building up somewhere in the production line. It is important not to expedite any parts at this point in time; otherwise the organisation will have to continue to expedite different parts at different periods in time.

The reason for the parts increasing in front of the constraints or at assembly is because priority was given to all constraint parts ahead of the constraint. Parts at constraints have increased, because everybody ahead of the constraint is giving priority to these parts

Goldratt and Cox (1992:165) define the following:

X = Constraints

Y = Non-constraints (These have extra capacity and are faster in filling the demand)

The capacity of the constraint is matched with the market demand at 600 hours

The equivalent rate that the non-constraints have to produce in order to provide parts for the constraint or assembly is 450 hours, because they have a higher capacity.

Goldratt and Cox (1992:203) explain that there are four possible linear relationships between constraints and non-constraints:

**Scenario #1** – non-constraints are in front of constraints

Y → X

450h 600h

X needs 600h to fill the demand, but Y only needs 450h. If y works 600h, excess inventory will result.

**Scenario #2** – Constraints are in front of non-constraints

X → Y  
600h 450h

X needs 600h to fill demand, but Y only 450h. Y will not be able to work 600h, because there will be no parts coming from X to work on. If Y works on anything else in the remaining 150h, excess inventory will result.

**Scenario #3** – Constraint and non-constraints provide directly to assembly.

Y → A  
X → S  
S  
E  
M  
B  
L  
Y

If X and Y work continuously, how efficient will the system be? According to Goldratt and Cox (1992:170), the answer is simple: Final assembly will still wait for constraint parts and will not be able to assemble. This will cause excess inventory at the assembly instead of in front of constraint.

**Scenario #4** – Products come only from constraints or only from non-constraints

Y → Product A

Y has excess capacity (more than the market demand). When Y is worked to the maximum (600h) there will be excess inventory of product A. It will be excess finished goods, instead of in-progress work.

X → Product B

When X is worked to the maximum, it will meet market demand.

Goldratt and Cox (1992:172) arrived at the following conclusions:

- Y (non-constraint) never determines throughput for a system; and
- When Y is activated above the level of X, it results in excess inventory, not increased throughput

In order to prevent the above-mentioned scenarios from happening in a production line, Goldratt states the following rule:

*“Activating a resource and utilising a resource are not synonyms”* (Goldratt & Cox 1992:208).

**Utilising** a resource means making use of the resource in a way that moves the system towards *The Goal*

**Activating** the resource is like pressing the on switch of a machine. It runs whether or not there is any benefit to be derived from the work that is being done.

The level of utilisation of a non-constraint is not determined by its own potential, but by some other constraint in the system. Therefore, if any machine works faster than the constraint, it is not increasing *productivity*, but actually increasing *inventory*, which is against *The Goal*.

The question of idle time arises here. Non-constraints cannot merely wait for constraints to finish. Goldratt and Cox (1992:210) explain that by keeping people busy just for the sake of keeping them busy will create inventory, which goes against *The Goal*. Making an employee work and profiting from that work are two different things. The system will not benefit from optimising single resources: “A system of local optimums is not an optimum system”(Goldratt & Cox, 1992:215). In order to keep all resources working at the same rate as the constraints, material must be released according to the rate that the constraints can manufacture – not faster. The constraint therefore determines the production tempo.

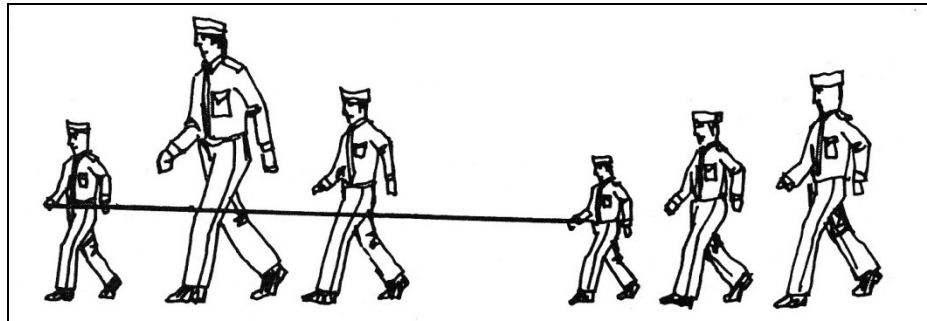
### **2.1.5. Drum-Buffer-Rope (DBR)**

Different methods were discussed regarding how to identify and optimise the constraints, but how should the rest of the plant be optimised relative to the constraint?

### 2.1.5.1. The troop analogy

Referring back to the troop analogy, it can be stated that it is not always possible to arrange the resources according to their capacity in a production line.

If the soldiers are not arranged with the slowest one in front, but rather in a random fashion (as is the case in a true plant scenario) and the front soldier moves faster than the slowest one, the troop will spread. If we tie a rope from the front soldier to the slowest soldier the troop will not be able to spread (see Figure 2-3).



**Figure 2-3: Troop analogy: Drum-Buffer-Rope**  
Source: Goldratt & Fox (1986:97)

The soldiers following the weakest soldier will be able to march faster than him and will therefore always be on his heels. Thus, no spreading will occur behind the weakest soldier. The front soldier can march faster than the weakest soldier but he is constrained by the rope (no spreading occurs). The soldiers between the first one and the slowest one are able to march faster than the weakest one (and the front one that is constrained by the rope) and will therefore always be on the heels of the front one (again, no spreading). The only gap or spreading that will occur is right in front of the weakest soldier. The size of this gap is predetermined by the length of the rope.

Goldratt and Fox (1986:96) explain the advantages of the system in the following manner: suppose one of the soldiers following the weakest soldier drops his gun. This will not affect the weakest soldier. Temporary spreading will occur because of the disruption, but since the soldiers that follow are stronger (have more capacity) than the weakest soldier, they will be able to catch up to the weakest one and close the gap. Although temporary spreading (excess inventory) will occur, it will not influence the progress of the entire troop (throughput).

If a soldier preceding the weakest one drops his gun - as long as he picks it up before the weakest soldier closes the gap - there will be no impact on the troops movement. The gap in front of the weakest soldier serves as a buffer against disruption from the preceding soldiers (production resources). By implementing this system, current throughput is protected, future throughput is enhanced, operational expenses are not endangered (no more soldiers are needed) and inventory is reduced.

### 2.1.5.2. Marching soldiers in a plant

In a plant there are only a few capacity constraint resources (CCRs) According to the DBR (Drum-Buffer-Rope) way such a constraint will dictate the rate of production of the entire plant. Therefore the constraint will be the **drummer**. Its production rate will serve as the drumbeat for the entire plant. An inventory buffer needs to be established in front of the CCR that will keep it busy during the next predetermined time interval. This buffer is called a time **buffer**. This time buffer will protect the throughput of the plant against any disruptions that can be overcome within the predetermined time interval.

Inventory must never grow to beyond the level that is dictated by the time buffer. This is controlled by the rate that raw material is released into the plant. A **rope** should be tied from the CCR to the first operation of the plant. In other words, the rate at which the first operation is allowed to release material into the plant is dictated by the rate that the CCR is producing. The Drum-Buffer-Rope approach is graphically explained in Figure 2-4.

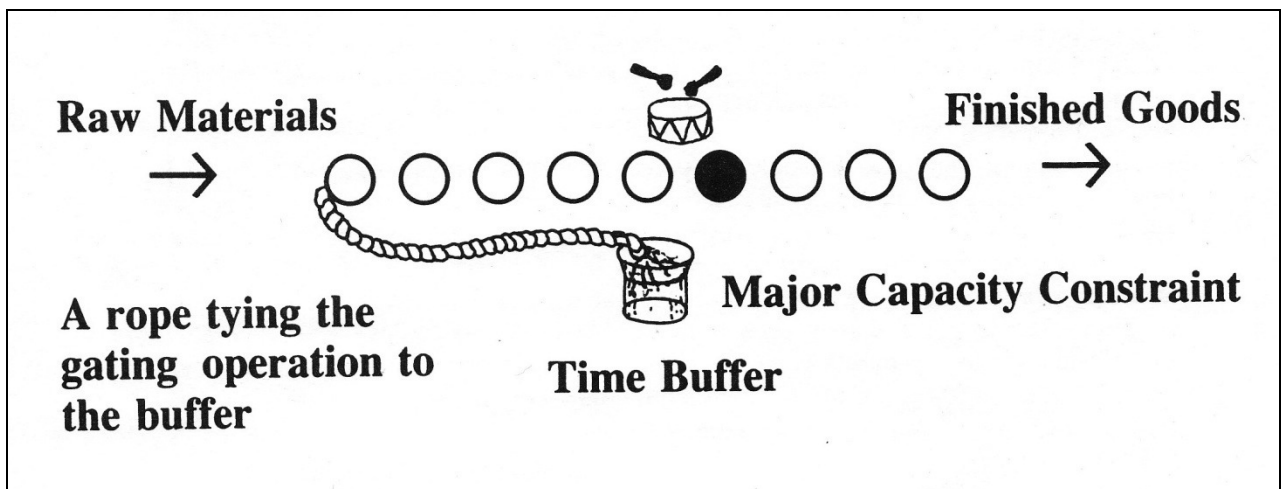
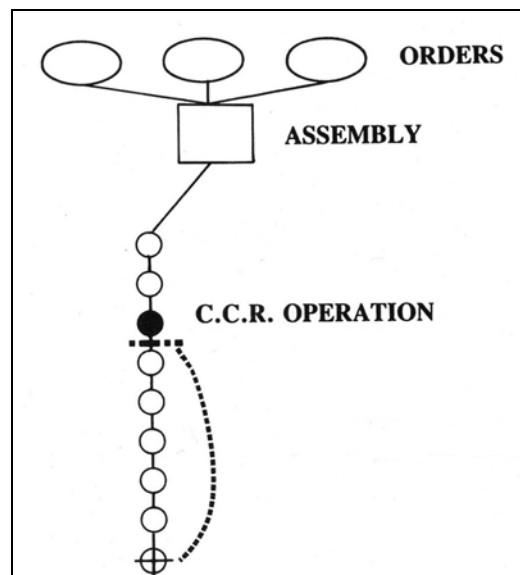


Figure 2-4: The Drum-Buffer-Rope way  
(Goldratt & Fox, 1986:99)

In order to explain the application of the DBR way in a plant, a part will be considered that proceeds through several operations with only one of them being a CCR. The part will eventually be assembled with other parts into a finished product for shipment to several different customers. According to Goldratt and Fox (1986:100) the two major constraints in a plant are the market demands (the amount of product that is sold) and the capacity of the CCR. Therefore it makes sense to base the schedule (logistical flow) on these two constraints.

The first step is to determine the schedule of the CCR, taking into account only its limited capacity and the market demand. Once this schedule has been established, the schedules of the other non-constraining resources need to be determined. It is relatively easy to schedule the succeeding operations: once a part is finished at the CCR, it is scheduled to start the next operation. Each subsequent operation (including assembly) is started as soon as the previous operation has been completed.

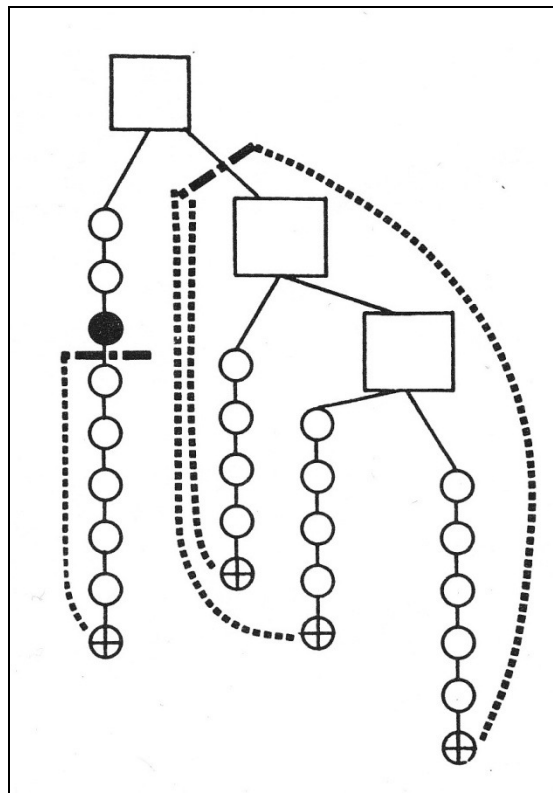
The challenge is to schedule the preceding operations and protect the CCR from disturbances. If a buffer of for example three days is implemented, the task immediately preceding the CCR is scheduled to complete operations three days before it is scheduled to run on the CCR. Each of the preceding operations is back-scheduled in such a manner that the parts are received just-in-time for the subsequent operation (Figure 2-5).



**Figure 2-5: DBR system - Single assembly line**  
(Goldratt & Fox, 1986:101)

The DBR system will protect the throughput of a plant, but meeting customer due-dates are equally important. The assembly schedule is dictated by the availability of the scarce parts coming from the CCR. Thus, the availability of these parts determines the shipment to customers.

When an assembly operation is fed by parts coming from a CCR as well as parts coming from non-constraining resources, the assembly operation should also be protected from disruption caused by the non-constraining resources. Therefore, a buffer should be built in front of the assembly line between the non-constraining resources and the assembly (Figure 2-6).



**Figure 2-6: DBR: multiple assembly lines**  
(Goldratt & Fox, 1986:103)

If a buffer of, for example, three days is used again, the parts coming from the non-constraining resources should also be back-scheduled to finish three days before it is required at the assembly operation.

In this regard it should be noted that time buffers are not required before every assembly operation. They are only required before assembly operations that are fed by CCR and non-CCR parts and in front of the CCR itself. In this way, a part will cross, in its journey from raw material to finished goods, no more than one buffer.

“The concept of the DBR logistical system is quite clear, but the complexity of Figure 2-7 illustrates why we will need the aid of a computerised system. Even though the calculations are quite straightforward, to perform them manually in almost every plant is very time consuming and requires heavenly patience” (Goldratt & Fox, 1986:104).

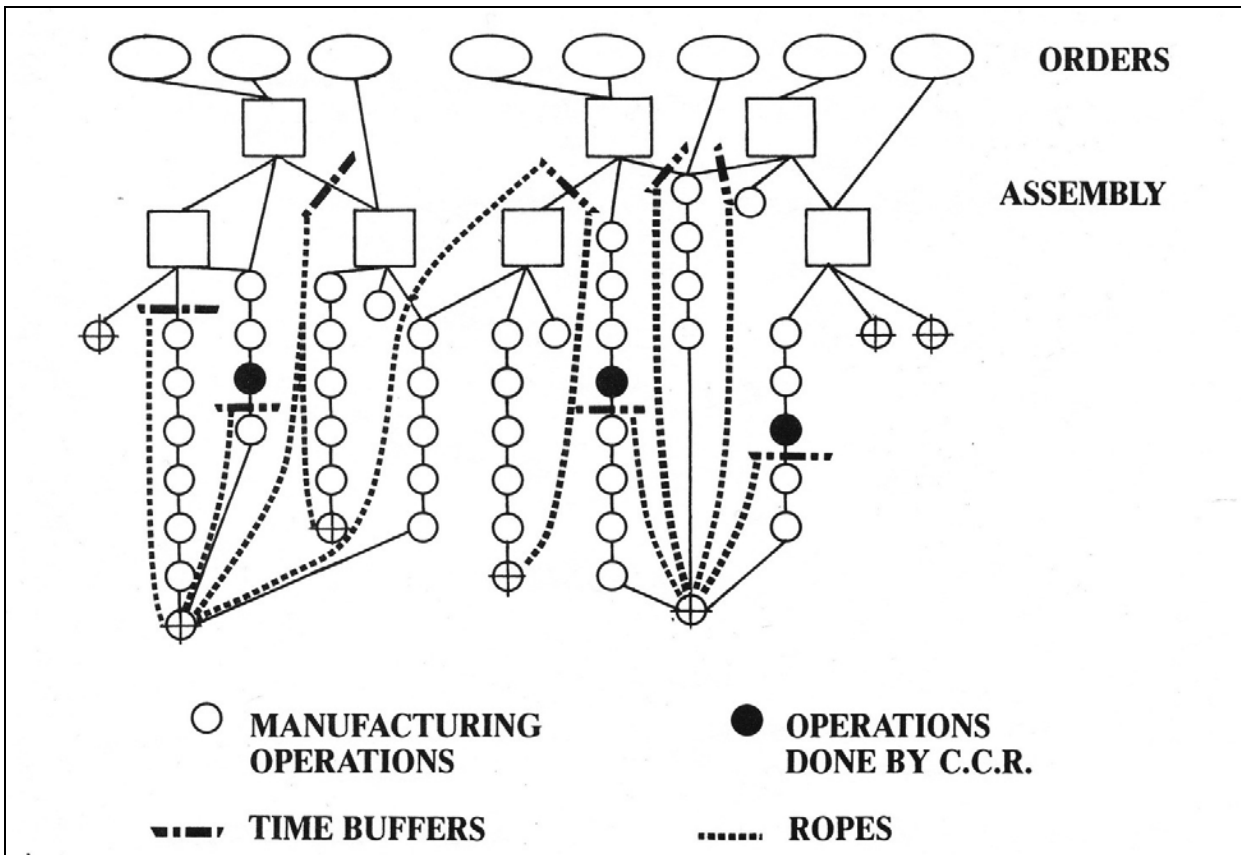


Figure 2-7: Synchronised manufacturing: the Drum-Buffer-Rope way  
(Goldratt & Fox, 1986:105)

### 2.1.5.3. Beating the drum

The CCR limits the throughput of the plan and controls due-date performance. Therefore the following must be ensured:

- The CCR must not be scheduled to produce more than its capacity;
- The capacity of the CCR cannot be wasted by allowing slack in the schedule; and
- Production at the CCR must be sequenced in such a manner that it will result in good due-date performance.

In order to accomplish these goals the sequence in which the work is done at the CCR can be scheduled according to customer due dates. Products that need delivery first must be worked on first. This is a sound approach, except in the following cases:

1. **When lead time from the CCR operations to completion differs greatly** – There might be a product A that, once it is completed by the CCR, requires only three days of additional work before it can be delivered. Product B, on the other hand, requires ten days of additional work. Then it may be sensible to schedule Product B (which is due for delivery next week) before Product A that is due for delivery this week.
2. **When one CCR is feeding another CCR** – When keeping to the customer due-date sequence, it could happen that second CCR is starved. When time is lost at any one CCR, throughput of the entire plant is lost.
3. **When setup time is high and changing resources requires time** – If this occurs when changing between products at the CCR, it may be wise to make a single production run in order to satisfy the market demand of a particular product for several days.
4. **When a CCR is producing more than one part for a product** – In this case all the parts have the same due date.

According to Goldratt and Fox (1986:110) choosing a good sequence for the CCR is very complicated. However, sound rules can be established and incorporated into a computerised system. The real importance, however, is found in the overall application of the DBR method, rather than in the precise way that the drum is beaten.

#### 2.1.5.4. The Ropes

Material is released and processed according to the schedule determined by the plant constraints. Therefore under no circumstances should material be released simply to supply work to workers. According to Goldratt and Fox (1986:114) the Japanese have an advantage because they have gone through this culture shock under the *kanban* system (the Just-in-Time scheduling system), as long as a worker does not have a *kanban* card he does not produce parts. He stands idle no matter how expensive that machine, how highly-paid the worker or how expensive the half-processed parts sitting in front of the machine. (The *kanban* system is explained in detail in the last paragraph of Principle 3 in Section 2.2.5.2 of this dissertation.).

#### 2.1.5.5. The Buffers – A process of focused ongoing improvements

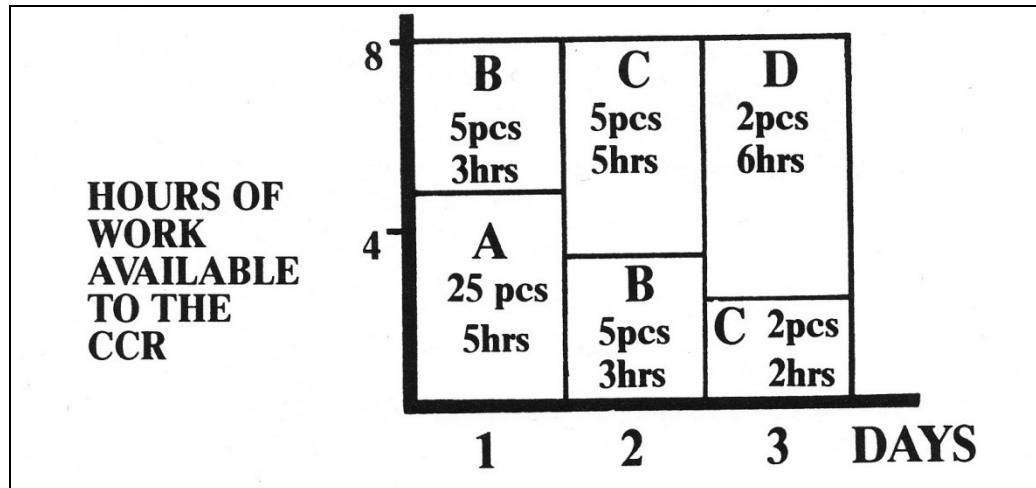
“The results of installing the DBR system and the relative short time required to achieve such outstanding benefits are truly impressive. However, a DBR system will not enable a company to stay in or lead *The Race* for long” (Goldratt & Fox: 1986:116).

The buffers therefore need to be managed in order to locate and quantify the importance of the disruptions in a plant. Correcting the highlighted disruptions, the continual usage of the drum-buffer-rope approach to a synchronised flow and managing the buffers will enable a plant to establish an ongoing, focused process of improvement – a productivity flywheel.

The following example will illustrate how to use the buffers with a view to establish an ongoing, focused process of improvement:

Suppose the schedule for the CCR has been set for a week. Different parts in different quantities are required. A buffer of three days is chosen. On the Monday, the parts that needs to be processed on Monday, Tuesday and Wednesday, must be waiting in front of the CCR. No other parts should be there, because these will not add to the protection and will only reduce the plant’s competitive edge in *The Race* (excess inventory).

Figure 2-8 illustrates the buffer as a rectangle. The vertical axis is the number of hours that a particular part will require of the CCR and the horizontal axis measures when (on which day) these parts are scheduled for processing by the CCR.



**Figure 2-8: The time buffer**  
(Goldratt & Fox, 1986:119)

The content of the buffer is continuously changing, because on Tuesday morning the parts that need to be processed on Tuesday, Wednesday and Thursday must be in the buffer. Monday's part must have been completed and Friday's part must not yet be there. According to Goldratt and Fox (1986:120), this concept of a revolving inventory in the buffer is vastly different from the usual understanding of safety stock as a constant inventory level of each part.

The purpose of a buffer is to protect the throughput and due dates of a plant against disruptions. If a buffer is always full, there are clearly no disruptions and the buffer is actually not required. The inventory in the buffer can be eliminated without damaging the throughput and this will reduce the operating expenses.

Furthermore, the actual buffer in front of a critical operation should not be the same as the planned buffer. The desired planned and actual buffer pattern is illustrated in Figure 2-9.

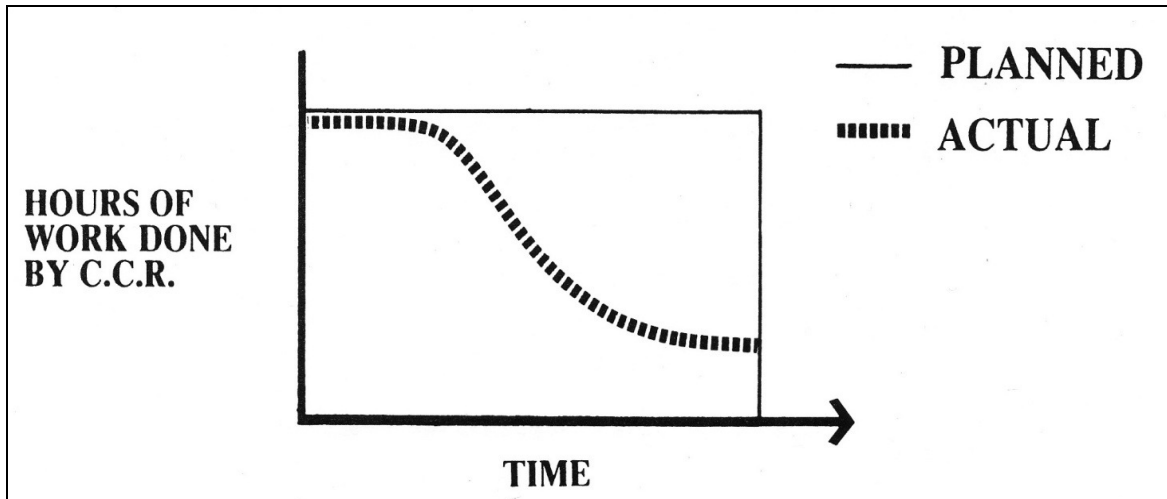
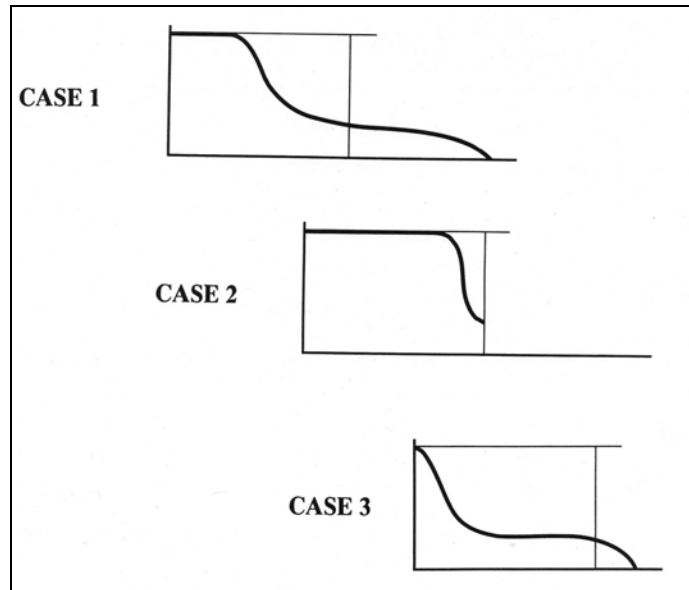


Figure 2-9: Desired planned vs actual buffer pattern  
(Goldratt & Fox: 1986:123)

The first third of the buffer should always be full, because these are the parts that are required first by the CCR. Most material planned for the last third should be absent. Actual versus planned content of the middle third of the buffer, should be somewhere in between these two extremes “The buffer profile should protect our critical operation from all but the most extreme fluctuations” (Goldratt & Fox, 1986:122).

The following three examples will illustrate how the actual content of the buffer can differ from the desired content (Figure 2-10):

1. **The pattern of the actual buffer stretches beyond the planned buffer** – Material is being produced earlier than called for by preceding operations. More education and discipline are needed at the first operation.
2. **The buffer is almost full** – The planned buffer is too large. Therefore a too high premium of insurance is being paid. The size of the planned buffer should be cut so that on the first third is full.
3. **The totally filled portion is less than the first half** – The buffer is too small and the risks is that the CCR could be starved causing the plant to lose throughput. The buffer needs to be increased until the first third is completely full.



**Figure 2-10: Buffer management**  
(Goldratt & Fox, 1986:125)

It is clear why it is important to have the appropriate amount of “emptiness” in the buffer and where it should be located.

Goldratt and Fox (1986:134) summarises the advantages of buffer management as follows: “As the buffers are decreased, the competitive edge of the plant is increased. Lead times, operating expenses and inventory investment will decrease while quality, due-date performance and the speed of introducing improved products will increase. The market demand will increase, which will lead to an increase in throughput, which will be very profitable since a commensurate increase in operating expenses and inventory is not required. Net profit, return on investment and cash flow will increase simultaneously. The plant will be moving in the direction of *The Goal*”.

### 2.1.6. The next logical steps

After the constraints have been identified and addressed and after the DBR system has been implemented, Goldratt introduces “the next logical steps” (Goldratt & Cox, 1992:206):

**Step #1** – Reduce batches sent through non-constraints to halve the size.

When the batch sizes are cut in half, the work in progress is cut in half. This will lead to only half the inventory at any given point in time, which will reduce the amount of cash tied up in the organisation. This will increase cash flow.

The time that parts spend inside the factory can be divided into four sections:

1. **Set-up / preparation time**
2. **Process time** – The time parts spend being transformed into a new, more valuable form
3. **Queue time** – The time parts spend waiting for a resource while he is working on something else
4. **Wait time** – The time parts spend waiting for another part so that they can be assembled together

The set-up time and process times only take up a small portion of the parts time, while parts spend the majority of their time in queue time and wait time.

For parts that proceed through a constraint, the queue time is the dominant factor. This means that for parts that only go through non-constraints, wait time is the dominant factor, because they have to wait in front of assembly for parts coming from constraints. Therefore, constraints determine elapsed time, which in turn means that they actually dictate inventory and throughput.

When batch sizes are reduced, process time is reduced together with queue time and wait time. This implies that the time that the parts spend in the plant is reduced. This will cause total lead times to be condensed and this, in turn, will lead to faster turnaround on orders and customers will get their orders faster. The organisation will be able to respond faster to the market, which will give them an advantage in the market. They will be able to attract more customers, because they will be able to deliver faster. Ultimately, their sales will increase.

Although an hour lost at a constraint is an hour lost to the entire system, an hour saved to a non-constraint is an illusion. The system does not benefit from saving an hour at a non-constraint, because constraints determine throughput.

By reducing batch sizes, set-up time at the non-constraint will increase. This will, however, not have an effect on the system because the idle time of the non-constraints will be used (non-constraints have higher capacity than constraints, i.e. more available time). The idle time at each non-constraint will be spread into smaller parts over the duration of time.

**Step #2** - Increasing marketing: promise earlier delivery (Goldratt & Cox, 1992:229)

After the batch sizes have been reduced and the turn-around time decreased, the customers will be able to receive their orders faster. Therefore, this fact should be marketed to the customers in order to increase the market demand and increase sales.

### **2.1.7. Fundamental erroneous assumptions**

Goldratt and Cox (1992:232) explain that the following are incorrect assumptions that are made by organisations:

1. Balance capacity with demand first, and then try to maintain the flow.

Instead of balancing capacity, the organisation should have excess capacity. The flow should be balanced with capacity.

2. The level of utilisation of any worker is determined by his own potential.

This assumption is false because of dependencies. For any resource that is not a constraint, the level of activity from which the system is able to profit is not determined by its individual potential, but by some other constraint in the system

3. Utilisation and activation are the same.

This is erroneous. Utilising a resource means making use of the resource in a way that moves the system towards *The Goal*. This is not the same as simply activating the resource. Activating the resource is like pressing the 'on' switch of a machine to make it run whether or not there is any benefit to be derived from the work that is being done.

4. An hour saved at a non-constraint is an hour saved for the system.

This is false, because throughput is determined by the constraints. Saving an hour at the non-constraint has no influence on saving time at the constraints and will therefore have no effect on saving time of the system.

5. Constraints have little influence on inventory.

This assumption is wrong. Constraints govern throughput and inventory.

### 2.1.8. A process of ongoing improvements

After improving an organisation and working towards *The Goal*, a process of ongoing improvement must be implemented.

According to Goldratt and Cox (1992:240), organisations conventionally tend to measure their performance according to the following (in order of importance):

1. Operating expenses;
2. Throughput; and
3. Inventory.

On this scale operating costs are seen as the most important factor. The constraint concept for improvement is not based on reducing costs, it is rather focused on increasing throughput. According to Goldratt and Cox (1992:241), the scale of importance should be switched to the following:

1. Throughput;
2. Inventory – Due to impact on throughput; and
3. Operating expenses.

The organisation should therefore move from the cost world to the throughput world.

According to Goldratt and Cox (1992:243), not all problems that organisations experience are caused by internal constraints. The organisation could experience difficulties due to external factors such as a decrease in market demand. This could have the same results as constraints, but it is more unambiguous to refer to all problems experienced by organisations, as *constraints*. In reference to this, Goldratt and Cox (1992:203) explain the process of ongoing improvement as follows:

1. Identify the system's constraints.
2. Decide how to exploit the system's constraints.
3. Subordinate everything to the above decision.
4. Elevate the system's constraints.
5. WARNING: if in the previous stage a constraint has been broken, go back to step 1, but do not allow inertia to cause a system constraint.
6. If in a previous step a constraint was broken, go back to step 1.

### 2.1.9. Common sense

After writing the book *The Goal*, Goldratt (1992:150) came to the realisation that all the answers to improving an organisation were based on common sense. Why was it then that people needed a trigger to set it off? Why could everyone not just realise all the answers by themselves?

According to Goldratt (1992:150) the definition for common sense is as follows:

“Something is in line with our own intuition, something that we already knew intuitively.”

He realised the answer to his question:

*“Intuitive conclusions are masked by something else, something that is not common sense – common practice”.*

## **2.2. The Toyota Lean Manufacturing System**

The principles of Lean manufacturing started in Japan, but Henry Ford had already noticed a similar phenomenon in the 1920's: "One of the most noteworthy accomplishments in keeping the price of Ford products low is the gradual shortening of the production cycle. The longer an article is in the process of manufacturing and the more it is moved about, the greater its ultimate cost." Henry Ford, 1926.

Henry Ford's original idea of continuous material flow was in line with Lean principles. Unfortunately, however, he used mass production to implement it. This prevented Ford from being flexible regarding customer requirements. This is also why the company turned out millions of black Model T's and later Model A's, using wasteful batch production methods that build up huge banks of work-in-progress inventory without the value chain, pushing product onto the next stage of production (Womack *et al.*, 1991).

Toyota saw this as an inherent flaw in Ford's mass production system.

### **2.2.1. What is Lean thinking?**

Lean thinking is concerned with creating an environment of continuous improvement, enabling quantifiable and sustainable change, while focusing on adding value and removing waste in order to increase customer satisfaction and profitability (Liker, 2004:15).

In 1988, Taichi Ohno (quoted by Liker, 2004:7) noted that: "All we are doing is looking at the timeline from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that time line by removing the non-value-added wastes."

The definition of Lean, as developed by the National Institute of Standards and Technology Manufacturing Extension Partnership's Lean Network is as follows: "A systematic approach to identifying and eliminating waste through continuous improvement and flowing the product at the pull of the customer in pursuit of perfection".

### **2.2.2. Lean definitions**

Any work that is done can be identified as either value-adding, non-value adding or waste. These concepts can be defined as follows:

**Value-adding** – Any process that changes the nature, shape or characteristics of the product, in line with customer requirements.

**Non-value adding**, but unavoidable with current technology/methods – Any work carried out that does not increase product value.

**Waste** – All other meaningless, non-essential activities that do not add value to the product that can be eliminated immediately.

### **2.2.3. TPS vs. the Toyota Way**

The Toyota Production System is not the same as the Toyota Way: “TPS is the most systematic and highly developed example that the Toyota Way can accomplish. The Toyota Way comprises the foundational principles of the Toyota culture, which allows TPS to function so effectively”. (Liker, 2004:27). Although these concepts can be distinguished, the Toyota Way is directly responsible for the success, evolution and development of TPS.

### **2.2.4. The Lean temple**

In order to teach the Lean principles to their supply base, Fujio Cho developed a simple representation of Lean principles as a house. He used a house because it is a structural system and it is only strong if the roof, pillars and foundations are strong.

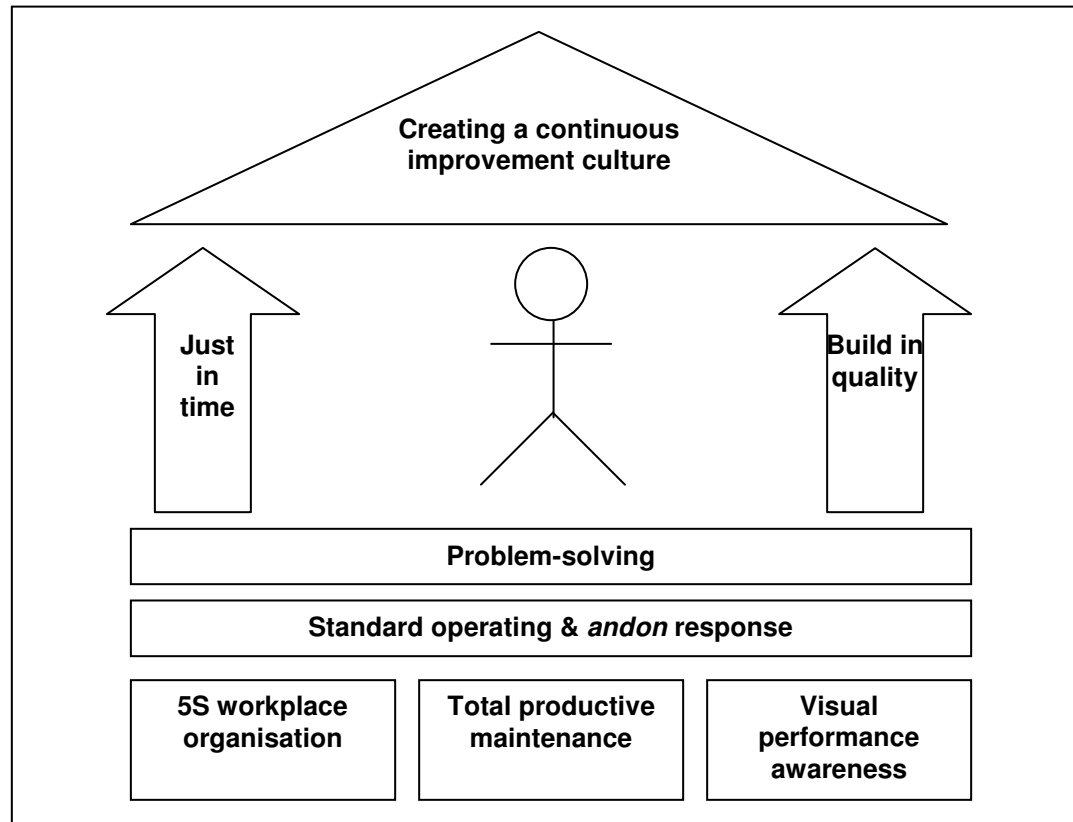


Figure 2-11: The Lean temple

According to Liker (2004:32), the TPS house is constructed as set out bellow.

The roof of the house represents the goal of the Toyota Production System:

- Best quality;
- Lowest cost; and
- Shortest lead time.

The two outer pillars represent:

- Just-in-time (JIT) – Delivering parts only as they are needed; and
- *Jidoka* – Not allowing poor quality to move into a next production station and freeing people from machines (automation with a human touch)

The foundation represents the need for:

- Standardised, stable, reliable processes; and
- *Heijunka* – Levelling out the production system in terms both volume and variety. This is necessary to keep the system stable and inventory at minimum levels.

The Lean system is seen as a temple (Figure 2-11) to present the following principles:

1. Without a foundation to create transparency all *kaizen* (continuous improvement) will fall apart;
2. Problem-solving must be built on standardisation;
3. The temple is build around the people; and
4. Leadership support the temple, it is the keystone for a culture of continual improvement.

According to Liker (2004:32) each element of the house is important, but it is even more important to note how the elements reinforce each other. JIT means removing as much as possible from the inventory that buffers production against problems. This implies that when a problem such as a quality defect arises, there will be no inventory to enable the system to continue and the problem becomes visible immediately. This reinforces *jidoka* which brings the production system to a halt. This means that workers have to resolve the problem immediately in order to be able to resume production.

The foundation of the house is stability. Ironically, the requirement to work with as little as possible inventory causes instability and a sense of urgency among workers. Unlike in the situation of mass production, there is no inventory to feed the system, while problems are resolved. Once a process is stopped to fix a problem, other processes will soon stop production due to a lack of parts. This causes a sense of urgency with everyone to stop and help fix problems together. When the same problems occur continuously, it will force management to investigate the root cause and solve that.

According to Liker (2004:32) people are at the centre of the house because it is only through continuous improvement that the system can reach stability. They need to be trained to see waste and solve problems at the root cause by repeatedly asking why the problem really occurs.

## 2.2.5. The 14 principles of the “Toyota Way”

After studying the Toyota Company for 20 years, Liker (2004:37) concluded that the Toyota Way is comprised of 14 principles. The principles can be divided into four categories, all starting with “P” (Figure 2-12).

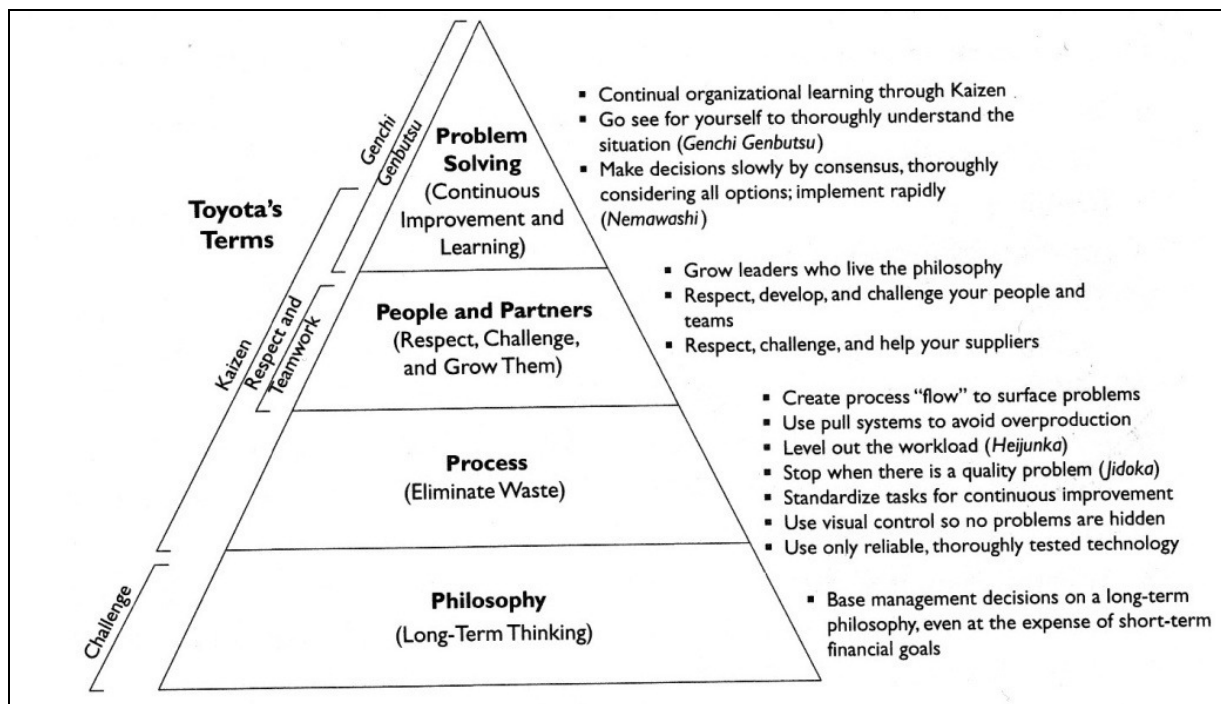


Figure 2-12: A "4P" model of the Toyota Way  
(Liker, 2004:6)

### 2.2.5.1. Philosophy – Long-term philosophy

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

An organisation needs to have a philosophical sense of purpose that supersedes any short-term goal. This purpose should be much larger than simply making money; it should grow and align the entire organisation to a common purpose. Employees should be informed, regarding what this purpose is, in order to ensure that everyone is moving in the same direction. Furthermore, every employee should understand their place in the history of the organisation and work to take the organisation to the next level. They should also understand their place in the organisation when it is in this next level.

The starting point of the organisation should be to generate value for the customer, society and the economy. Each activity that is performed in the organisation should be evaluated against this value. Employees should be made aware of what the customer requirements are and then focus on working towards these.

### **2.2.5.2. Process – The right process will produce the right results**

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

Work processes should be designed so that a high value-added, continuous flow is achieved. Flow means that when a customer places an order, the order immediately triggers a process where raw materials are sent to the workers to be manufactured into a product that is in line with what the customer requires. As soon as one worker has performed his job, the parts/material are immediately sent to the next worker. Once the product conforms to the requirements of the customer, the product is immediately sent to the customer. There should be no waiting or queues in between.

To this point, one needs to create flow in the organisation in order to move materials and information fast. At Toyota this means using small lots, keeping processes close to each other and keeping the material moving through different processes and people without interruptions. This is better than producing large batches of parts or materials and then having these sit and wait. Such mass-production methods will only create excess work-in-progress (WIP), increase inventory, tie-up cash-flow and create storage problems.

The system that Ohno set up does not assume that the ideal batch size is the one that is ideal for an individual process or worker. In Lean thinking the ideal batch is always the same – one. Ohno rather decided to optimise the batch size so that it would optimise the flow of material so that it would move quickly through the factory.

Figure 2-13 illustrates the difference between batch manufacturing and continuous flow production: One department makes all the squares in batches of five. When five squares are done, they send these to another department that adds the circles. Only when all five circles have been added, the batch is sent to the next department, who adds the triangles. If each operator takes one minute to complete his job, it will take a minimum of six minutes before the first assembly is produced, but only three minutes of value-adding time is spent per assembly. There

are at least 11 sub-assemblies in the process at any point in time and it takes 15 minutes to create five assemblies.

According to Liker (2004:93), work cells should be created that are grouped by product rather than by process. If Ohno were to manage this process, he would take one operator that manufactures the squares, one operator that assembles the circles and one operator that assembles the triangles and put them next to each other. That is, he would have created a cell to achieve one-piece flow. Then he would have made it clear that operators are not allowed to build up inventory. In other words, an operator is not allowed to produce more parts/sub-assemblies than is required by the next operator. The results of such an approach would be that it only takes three minutes before the first assembly is ready and three minutes of value-adding time is spent per sub-assembly. There would only be two sub-assemblies in process at any time and it would only take seven minutes to create five assemblies.

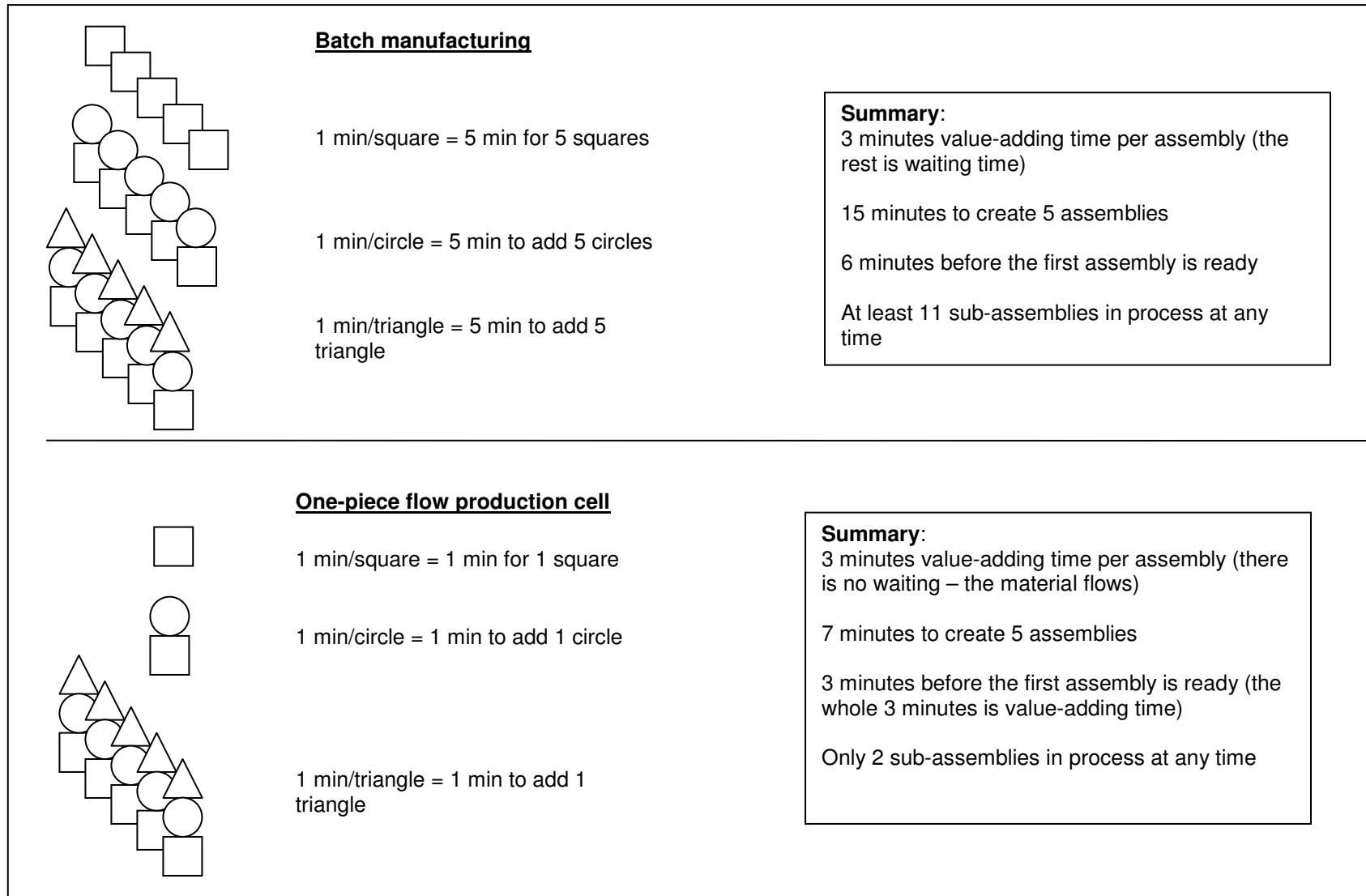


Figure 2-13: Batch production vs one-piece flow

Flow should be created with a view to link people and processes together so that problems surface immediately. Liker (2004:93) explains that people often think that increasing the speed of production will compromise quality, or that faster necessarily implies sloppier: “But flow achieves just the opposite – it generally improves quality”. When batch manufacturing is used and a defect is discovered, there are at least 11 sub-assemblies in process that might have the same problem. By contrast, with one-piece flow, there could only be two sub-assemblies in process at any time. The reality is that in batch manufacturing there are weeks of work in progress between operations and it can take weeks or even months from when a defect is caused until it is discovered. “By then the trail of cause and effect is cold, making it near impossible to track down and identify why the defect occurred” (Liker 2004:94).

According to Liker (2004:95) the following are the benefits of flow:

1. **Builds in quality** – Defects are detected easier and there are less work-in-progress that needs to be checked and repaired;
2. **Creates real flexibility** – Instead of putting in a new order into the system and waiting weeks to get that product out, if lead times are a few hours one can fill a new order in a few hours. Changing over to a different product mix to accommodate changes in customer demands can be almost immediate;
3. **Creates higher productivity** – There are few non-value adding activities;
4. **Frees up floor space** – Everything is moved closer together and little space is wasted by inventory;
5. **Improves safety** – Smaller batches of material and work-in-progress are being moved around in factories. This reduces the use of fork-lifts and trucks – a practice that increases safety in the factory;
6. **Improves morale** – People do more value-adding work and can immediately see the results of their work. This gives them a sense of accomplishment and job satisfaction; and
7. **Reduces cost of inventory** – When inventory is reduced, capital to invest somewhere else is untied.

When working with one-piece flow, the following question arises: Why should some inventory not be kept to make life easier? Liker (2004:99) explains that this approach hides problems and inefficiencies: “Inventory enables the bad habit of not having to confront problems and if problems are not confronted, the process cannot be improved. One-piece flow and continuous improvement go hand in hand”.

### **Principle 3: Use “pull” systems to avoid overproduction**

According to Liker (2004:105), “pull” means the ideal state of just-in-time manufacturing: giving the customer (which may be the next step in the production process) what they want, when they want it and in the amount that they want it. The leanest system would be to take a customer order and make a single product in a one-piece flow cell, because it is 100% on-demand and there is zero inventory in the organisation.

However, in a Lean organisation there will be inventory buffers: Instead of pushing the materials into the buffers according to a schedule, one merely looks at what has been used and replenish that before it runs out. Material replenishment should be initiated by consumption.

Ohno realised that inventory was necessary for smooth operations, but he also concluded that when individual departments build according to a schedule (as is the case with a push system), they will naturally overproduce and create large banks of inventory. This is because production is initiated by projected customer demands, but customer demands can change in a dime and things can go wrong. What should then become of the schedule? The organisation should be able to respond to customer demands rather than relying on schedules and sales forecasts.

As a compromise between one-piece flow and a “push”-system, Ohno decided to create small stores where goods are only replenished as they are used. When an internal customer takes away a part it is replenished, but when he does not use it, it remains in the store. This will result in no over-production and in there being a link between what the customer wants and what the company produces. Since companies are large and since stores and consumers are spread far apart, Ohno needed a way to signal that the assembly line had used the parts and needed more. He implemented the *kanban*-system (*kanban* means sign). He used simple cards, empty bins, and empty carts to signal the necessity for replenishment of parts.

It is important to understand that the *kanban* system is an organised system of inventory buffers that uses cards, empty bins and empty carts to signal when these buffers are running low. These signals are used to indicate shortages, instead of counting the stock that is available. It is therefore something good to implement, but it is also something one should strive to get rid of, since buffers are inventory that is not generating income. According to Liker (2004:110): “The challenge is to develop a learning organisation that will find ways to reduce the number of *kanban*’s and therefore finally eliminate the inventory buffer”.

**Principle 4: Level out the work load (*heijunka*) - Work like the tortoise, not the hare**

According to Taiichi Ohno (co-developer of Toyota Production System) non-value adding activities (*Muda*) account for up to 95% of all costs in non-lean manufacturing environments. These non-value adding activities can be identified as eight forms of waste. Seven of these wastes are more commonly experienced in organisations. These seven common faces of waste can be remembered by the acronym TIMWOOD (George, 2010:28)

1. Transport
2. Inventory
3. Motion
4. Waiting
5. Overproduction
6. Over processing
7. Defects

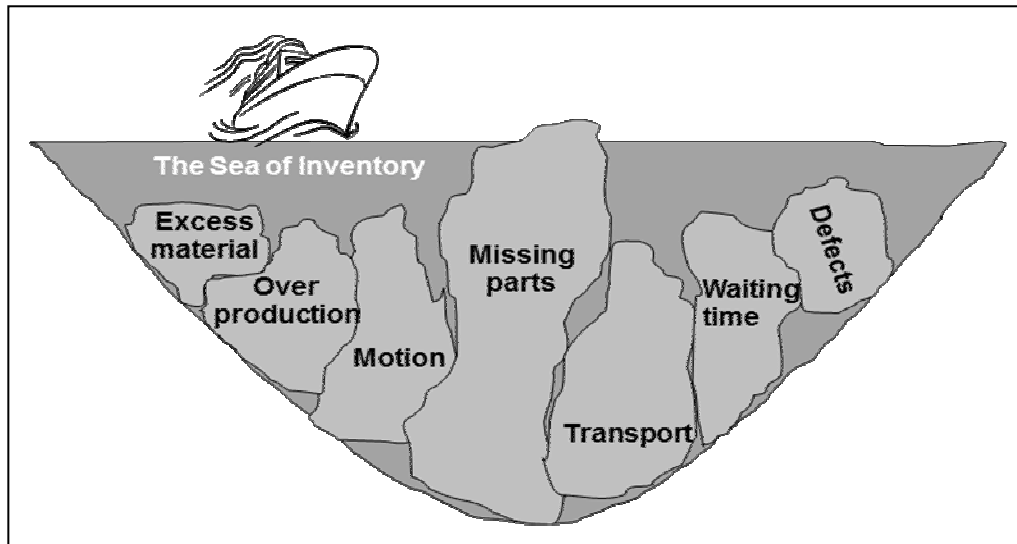
The eight forms of waste are described in greater detail as follows:

**1. Transportation**

Material and parts should be delivered at the point in the assembly line where it is used. Instead of raw material being delivered to a receiving location where it is processed, moved to storage and then distributed to where it is needed, it should be delivered directly to the location in the assembly line where it is used.

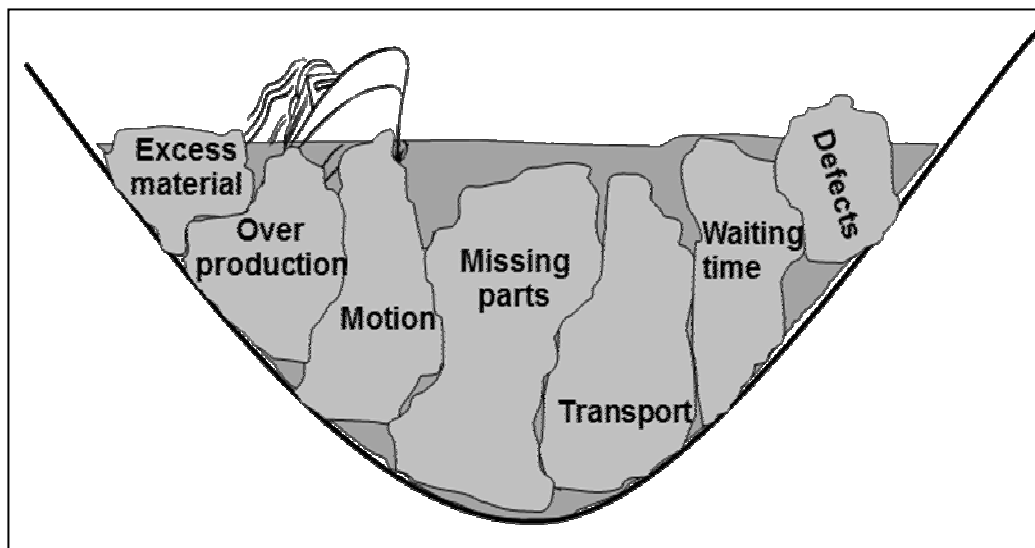
**2. Inventory**

Excess inventory is related to over-production. Anything that is beyond what is required by the customer negatively influences cash flow and wastes valuable floor space. Excess inventory also hides problems such as production imbalance, late deliveries from suppliers, defects, equipment downtime and long set-up times. Figure 2-14 shows how inventory can hide problems, preventing it from being solved.



**Figure 2-14: Sea of inventory**  
(Baker, 2009)

As soon as the inventory levels are lowered (and waste eliminated), the problems become visible and can therefore be solved. (Figure 2-15)



**Figure 2-15: Lower levels of inventory**  
(Baker, 2009)

According to Liker (2004: 29) examples of excess inventory are:

- Excess raw material;
- WIP (work in progress);
- Finished goods causing longer led times; and
- Damaged goods.

### **3. Motion**

According to Liker (2004: 29) examples of unnecessary movement are:

- Looking for...;
- Reaching for....;
- Stacking parts, tools, etc.; and
- Walking.

Unnecessary motion is caused by

- Poor work flow;
- Poor layout ;
- Poor housekeeping; and
- Inconsistent / undocumented work methods.

### **4. Waiting**

This includes waiting for

- Material;
- Information;
- Equipment; and
- Tools.

Lean demands that resources are provided on a just-in-time basis (JIT) – not too soon and not too late. According to Liker (2004:28), examples of waiting are:

- Workers appointed merely to watch an automated machine;
- Standing around waiting for the next processing step, tools, parts, etc.; and
- Having no work due to stock-outs, equipment down-time or capacity constraints.

### **5. Over-production**

Producing anything more than what is required by the customer, is regarded as waste. This generates extra costs for storage and transportation of inventory. Ohno considered over-production as the most fundamental form of waste, because it causes most of the other forms of waste.

## 6. Over-processing or incorrect processing

Examples of non-value added processing are the following:

- Reworking – The product should have been built correctly the first time;
- Deburring – The part should have been produced without burrs, with properly designed and maintained tools; and
- Inspection – Products should be produced with controlled processes, which limit the needs for inspection.

## 7. Not right the first time – scrap, rework & defects

Production defects waste resources time in the following ways:

- Materials are consumed;
- Labour that was used to build the part the first time cannot be recovered;
- Labour is required to rework the product; and
- Labour is required to address any forthcoming customer complaints.

## 8. Underutilisation of employee's creativity

People are the most important asset of any organisation. Therefore an organisation should:

- Engage the power of the brain not just the arm;
- Engage their employees to solve both their own problems and assist others in solving their problems. There should be true team work; and
- Engage their employees in the spirit of *kaizen* (continuous improvement).

*Muda* is the Japanese term for waste and most Lean manufacturing efforts focus on eliminating muda but there are two other M's that are just as important in order to make Lean work. It is important that all three should be addressed simultaneously. The three M's are:

- **Muda** - Non-value adding activities that appear in the eight forms of waste.
- **Muri** - Overburdening people and equipment. This is seen when a machine or person is pushed over its natural limits. Such practices give rise to safety and quality issues.
- **Mura** - Unevenness in production levels. Sometimes there is more work than the people or machines can handle, and at other times there is a lack of work.

Focusing on *muda* is the most common approach to “implementing Lean tools”, because it makes it easy to identify and eliminates waste. What many companies fail to do is the more difficult process of stabilising the system and creating evenness – a truly balanced Lean flow of work.

Instead of using the stop/start approach of working on projects, the work load should be levelled out for all manufacturing and service processes: *“The slower but consistent tortoise caused less waste and is much more desirable than the speedy hare that races ahead and then stops occasionally to doze. The Toyota Production System can be realised only when workers become tortoises”* (Taiichi Ohno, 1988, quoted by Liker, 2004:115).

*Heijunka* is the Chinese term for the levelling of production by both volume and product mix. The actual flow of customer orders can fluctuate over a period of time and products are therefore not built to actual customer orders. The total volume of orders that is produced over a period of time should rather be levelled out so that the same amount and mix of products are being made each day.

The initial approach of TPS is to make batch sizes as small as possible. With one-piece flow the company would build according to customer orders (for example, X X X Y Y Y X Y X X Y X ). The problem with this approach is that it causes the organisation to build parts irregularly. When orders are high, employees have to work overtime. If the orders are fewer the following day, they can be sent home early. In order to solve this problem, the actual customer demand is taken and a pattern of volume and mix is determined that can be followed each day: “This is called levelled, mixed-model production, because production is mixed up but it is also levelling the customer demand to a predictable sequence, which spreads out the different product types and levels volume” (Liker, 2004:116).

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

*Jidoka* is the second pillar of the TPS system. Quality needs to be built in. Therefore, when a defect is detected, it is important to be able to stop production and to solve the problem before it continues downstream. When machines are used, devices are built into these machines in order to detect abnormalities and stop the machine. In the case of people, they are given the power to push a button that will bring the entire production line to a halt. These buttons are called “*Andon* cords”.

The responsibility of producing quality parts are put into the hands of each team member, by giving them the responsibility to stop the production line every time they see something that is out

of standard. According to Alex Warren (quoted by Liker, 2004:129), employees then feel the responsibility – and feel the power that comes with responsibility. They know that they count.

*Jidoka* also is also referred to as *autonomation* – that is, equipment endowed with human intelligence able to stop itself when it has a problem: “In-station quality (preventing problems from being passed down the line) is much more effective and less costly than inspecting and repairing quality problems after the fact” (Liker, 2004,130). *Jidoka* (machines with human intelligence) is the foundation for “building in” quality.

Lean manufacturing focuses seriously on building things right the first time. With the low levels of inventory associated with Lean, there are no buffers on which to fall back in cases where a quality problem arises. This motivates employees to build parts right the first time so that they would not be the reason why the production line had to be stopped. When the line is stopped, flags or lights and alarms are used to indicate where help is needed to solve a quality problem. This signalling system is referred to as *andon*. *Andon* is designed for very short-cycle, repetitive jobs where immediate attention is needed and where seconds count (Liker, 2004:136).

It seems as there may be a paradox between the Lean principles. Toyota management says that it is acceptable to run at a rate lower than 100% even if they are capable of running full-time. “Toyota learned long ago that solving quality problems at the source saves time and money downstream. By continually surfacing problems and fixing them as they occur, you eliminate waste, your productivity soars and competitors who are running assembly lines flat-out and letting problems accumulate get left in the dust” (Liker, 2004:130).

Using the *andon* system does not mean that the whole production line is stopped if one cell pulls the cord. In Toyota, the *andon* is called a “fixed-position line stop system”. When the operator pushes the button to signal that a problem needs to be fixed, a light turns yellow. The team leader then has time to fix it until the vehicle moves into the next cell, and before the light turns red and the line segment stops. Team leaders have been carefully trained in terms of how to respond to a “call for help”. This means that either he is able to fix the problem before it needs to move to the next station or he notes that the problem can be fixed while the car is moving and pushes the button that cancels out the line stopping. Alternatively, the team leader concludes that the line has to stop. The assembly line is divided into segments with small buffers of cars in between. This allows the previous line segment to continue work when the following line segment has stopped. It

rarely occurs that the plant stops. The principle is that one should bring problems to the surface, make them visible and go to work immediately on countermeasures.

According to Liker (2004:135), at Toyota things are kept very simple but they use complex statistical tools. The quality specialist and team members have only four key tools:

1. Go and see;
2. Analyse the situation;
3. Use one-piece flow and *andon* to surface problems; and
4. Ask why five times.

Quality is everyone's responsibility in the organisation. Quality for the customer should drive the value scheme of the organisation, because adding value to the customer is what keeps the organisation in business and allows it to make money so that everyone can remain part of it. There must be a culture of stopping or slowing down to get quality right the first time in order to enhance productivity in the long run. All the aspects of the Toyota Way – the philosophy, process, partners and problem-solving – support this ability to “build in quality” and satisfy customers.

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

The foundation for pull and flow of parts and information is to maintain predictability, regular timing and regular output of the processes. This can only be achieved by stable, repeatable methods everywhere in the organisation.

Taiichi Ohno (as quoted by Liker, 2004:140) made the following statement: “Standard worksheets and the information contained in them are important elements of the Toyota Production System. For a production person to be able to write a standard worksheet that other workers can understand, he or she must be convinced of its importance. High production efficiency has been maintained by preventing the recurrence of defective products, operational mistakes, and accidents, and by incorporating workers' ideas. All of this is possible because of the inconspicuous standard worksheet.”

Henry Ford's perspective written back in 1926 fits well with the Toyota view: “Today's standardisation...is the necessary foundation on which tomorrow's improvements will be based. If

you think of 'standardisation' as the best you know today, but which is to be improved tomorrow...you get somewhere. But if you think of standards as confining, then progress stops. "(quoted by Liker 2004: 141)

Standardisation is not about finding the one scientifically-proven, best way of doing a task and then freezing it. Imai (1986) explained in his book *Kaizen*, that it is impossible to improve any process until it has been standardised. According to this author, if a process shifts from here to here, any improvement will just be another variation that is occasionally used. The process must be standardised which will also stabilise it before continuous improvements can be made.

According to Liker (2004:143) Standardised work is a key facilitator towards building in quality. An organisation cannot guarantee quality without standard procedures for ensuring consistency in the process. Furthermore, standardisation is the only way to ensure zero defects. When any defects are discovered at Toyota, the first question asked is 'which procedure was followed'. If it is found that the operator did follow the procedure correctly, the procedure needs to be revised.

The Toyota Way aims to enable those doing the work to design and build in quality by writing the standardised task procedure themselves. Any quality procedure has to be simple and practical enough to be used every day by the people doing the work. The accumulated learning about a process should be captured up to a point in time by standardising today's best practices. However, individuals should be allowed to be creative in order to improve upon standards. These improvements should then be incorporated into the standard.

### **Principle 7: Use visual control so that no problems are hidden**

The Japanese take pride in their work and therefore keep their factories clean. They implement "5S programmes" that comprise of a series of activities for eliminating wastes that contribute to errors, defects and injuries in the workplace. (Liker, 2004:150). The 5 S's (*seiri, seiton, seiso, seiketsu and shitsuke*) translated into English are:

- **Sort** – Sort through items and only keep what is necessary while disposing of the rest;
- **Straighten (orderliness)** – A place for everything and everything in its place;
- **Shine (cleanliness)** – The cleaning process often acts as a form of inspection that exposes abnormal and pre-failure conditions that could hurt quality or cause a machine failure;

- **Standardise (create rules)** – Develop system and procedures to maintain and monitor the first three S's; and
- **Sustain (self-discipline)** – Maintaining a stabilised workplace is an ongoing process of continuous improvement.

Managers play a critical role in the “sustain” part of 5S. According to Liker (2004:151), the programmes that are best sustained are those that are regularly audited by managers who use a standard audit form and often give symbolic rewards for the best team. One plant can be awarded the best team with a golden broom, which rotates to another team when they do better. In advanced Lean plants, work teams audit their own areas on a weekly or daily basis, and then managers inspects randomly.

The Toyota Way is not simply concerned with 5S-programmes and with cleaning up a plant. Visual control of a well-planned Lean system is different from making a mass-production system neat and shiny. According to Liker (2004:152), Lean systems use 5S to, “support a smooth flow to tact time, help make problems visible and be part of the process of visual control of a well planned Lean system”.

Simple visual indicators should be used to assist people to determine whether they are in a standard condition or if they are deviating from it: “Visual control is any communication device used in the work environment that tells at a glance how work should be done and whether it is deviating from the standard” (Liker, 2004:152). It will assist employees who want to do their job well to see immediately how they are doing. Information critical to the flow of work activities could be indicators that show where things belong, how many is required, what the standard working procedure is or the status of work in progress.

Examples of visual control are *kanban*, the one-piece flow cell, *andon* and standardised work. If there is no empty *kanban* (or a card) asking to be filled, it should not be filled. A well-organised cell will immediately indicate extra pieces of WIP through clearly marking the areas of the standard WIP. The *andon* cord signals a deviation from the standard operating conditions: “Toyota uses an integrated set of visual controls or a visual control system designed to create a transparent and waste-free environment” (Liker, 2004:153).

Using a computer screen should be avoided if it distracts the workers' focus away from the workplace. According to Liker (2004:157), Toyota was resistant regarding the implementation of the information technology-centric trend, because looking at a computer screen is usually associated with work done by one person in isolation. Working in the virtual world removes team members from hands-on team work and it usually takes one away from where the 'real' work is happening.

"The Toyota Way recognises that visual management compliments human beings, because they are visually, tactilely and audibly orientated" (Liker, 2004:158). Therefore, the best visual indicators are those that are right at the work place where they can jump right out at one by means of sound, sight, and feel. It will indicate the standard clearly as well as any deviation thereof: "A well-developed visual control system increases productivity, reduces defects and mistakes, help meet deadlines, facilitate communication, improves safety, lowers cost and generally gives the workers much more control over their environment" (Liker, 2004:158).

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

According to Liker (2004:160), new technology is only introduced at Toyota after such technology has been tried and tested by means of direct experimentation and with the involvement of a broad cross-section of people, with a view to ensure that technology would indeed provide added value. Before anything is implemented, Toyota undertakes a thorough analysis in order to ascertain the effects that a new technology will have on the current processes. This analysis proceeds through a number of steps:

1. See firsthand the value-added work that is performed by the worker in the particular process. Here one will look for new opportunities to eliminate waste and even out the flow.
2. Toyota uses a pilot area to improve the process with current technology, equipment and people.
3. When they have made all the improvements possible with the current technology, they will ask the question again (whether they can make any improvement by means of new technology).
4. If it is found that new technology can indeed improve the process, the technology is evaluated in order to ensure that it is not in conflict with Toyota's philosophies and operating principles. These include principles of valuing people over technology, using consensus decision-making and an operational focus on waste elimination.

5. If the technology violates these principles or if there is any chance that it may adversely disrupt stability, reliability, and flexibility, Toyota will reject the idea or delay implementation thereof until the problem can be solved.

“If the technology is acceptable, the guiding principle is to design and use it to support continuous flow in the production process and help employees perform better within the Toyota Way standards. This means that the technology should be highly visual and intuitive” (Liker, 2004:160). The important principle in this regard is that one needs to find a way to support the actual work while not distracting people from their value-adding work. It is therefore ideal that the new technology should be applied directly at the workplace and it should not involve someone in an office to input the data.

Once Toyota has proceeded through the steps of the process, they will quickly implement the new technology. Because they follow such a painstaking process, they will be able to implement the technology smoothly without any resistance from the employees or process disruption (Liker, 2004:160).

The following guidelines are used at Toyota when implementing new information technology:

- One should use technology to support people, not to replace them.
- A new process should be worked out manually before adding technology to support it.
- When a process works, one should not change it simply for the sake of adding new technology, because new technology can be unreliable.
- One needs to conduct actual tests before implementing new processes or technology
- One should reject or modify technology that is in conflict with the culture of the organisation
- Furthermore, one should reject technology that could disrupt stability, reliability and predictability.
- Finally, one should encourage people to investigate the use of technology if this could increase flow.

### **2.2.5.3. People / Partners – Add value to the organisation by developing the people & partners**

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

In 2002, the Automotive news wrapped up the year by recognising the biggest newsmakers in the industry. The difference between the non-Toyota leaders and Fujio Cho (then President of Toyota), was that the non-Toyota leaders did not naturally progress through the promotions to become CEOs or presidents: “They abruptly came in from the outside to change the culture, to shake up and change the direction of a company that was going bad” (Liker, 2004:172).

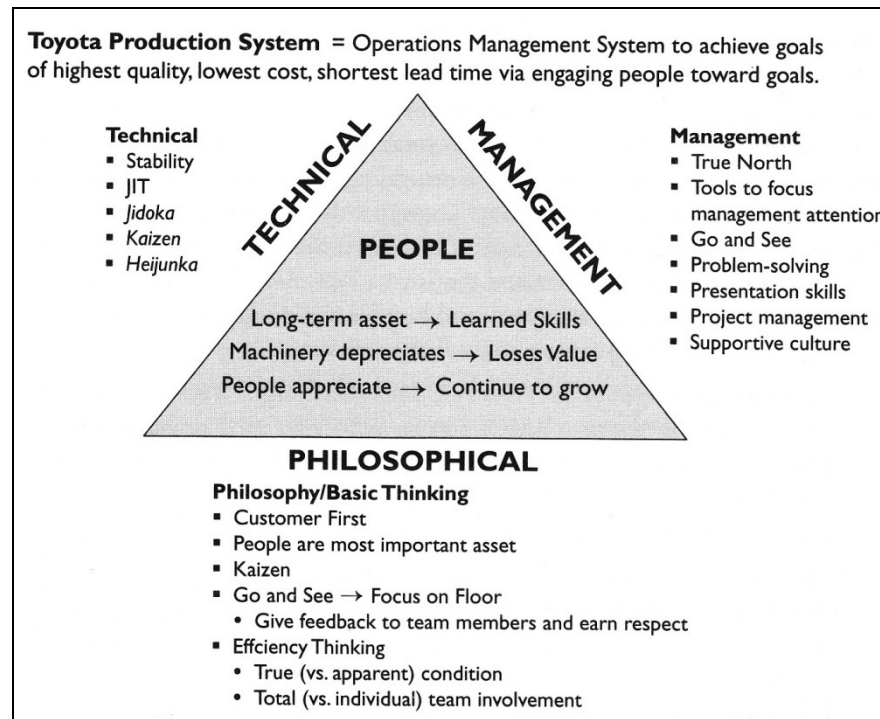
According to Liker (2004:172), Cho, in contrast to the others, grew up in Toyota and was a student of Taiichi Ohno. He and Ohno provided a theoretical basis for the Toyota Production System and the Toyota Way principles in order to teach these throughout the company. Cho moved into the position naturally and built on momentum that had been developing for decades. At Toyota it is not necessary for the new CEO or president to come in and take charge to move the company into a radically new direction in order to make his imprint on the company.

The belief is therefore that instead of buying leaders from outside of the organisation, they should rather be grown from the inside. Toyota also expects its leaders to teach the Toyota Way to their subordinates, which means that they must understand and live the philosophy. Also, leaders must be role models of the company’s philosophy and way of doing business; they do not only have to have good people skills.

Changing the culture of a company each time a new leader is appointed means that the company gets jerked around without developing a real depth or loyalty from the employees. Therefore, one of the problems associated with an outside leader that radically shifts the organisation each time is that the employees never learn. They will lose the ability to build on achievements, mistakes, or enduring principles. This will affect the ability of the leaders to make effective changes.

Gary Convis was the first American president of Toyota Motors. According to Liker (2004:174), it took Toyota executives 15 year to develop Convis into someone they could trust to carry the Toyota banner. He was appointed at NUMMI which was also the first American Toyota plant.

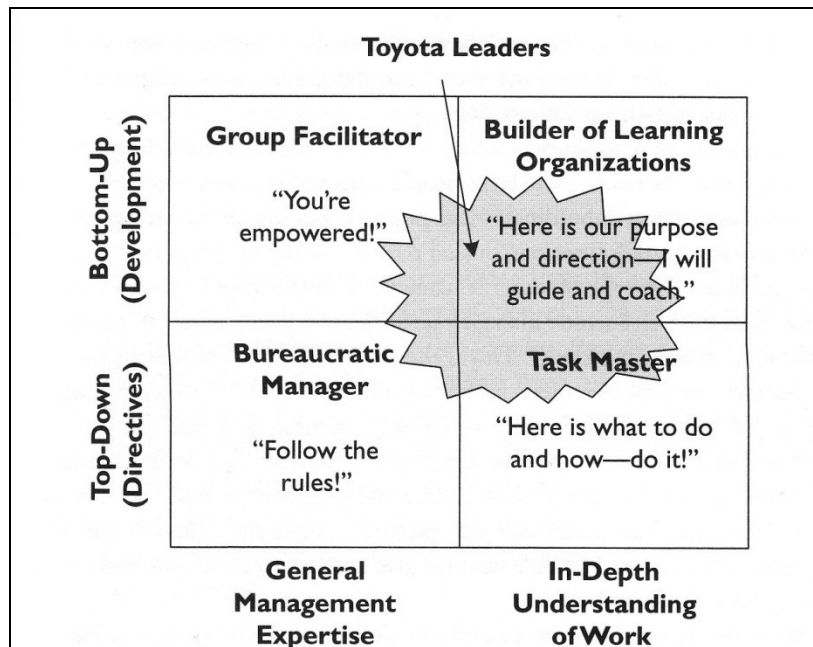
According to Convis (quoted by Liker 2004: 175), TPS is a three-dimensional beast where only one spike includes the technical tools often associated with Lean production – JIT, *jidoka*, *heijunka*, and the like. These are, however, only technical tools and can only be effective with the right management and the right philosophy – the underlying way of thinking. At the centre of TPS are people. Figure 2-16 illustrates how Gary Convis sees TPS.



**Figure 2-16: A Toyota leader's view of the TPS**  
Source: Gary Convis, President of TMMK (Liker 2004:176)

Good leaders need to have a very sound understanding of the nature of daily work so that they can be the best teachers of the company's philosophy. According to Liker (2004:180) the different forms of leadership can be explained by means of a two-dimensional matrix (Figure 2-17). Leaders can either rule by top-down directives or by means of a bottom-up, more involving style that is concerned with developing people so that they can think and make the right decisions on their own.

Toyota leaders are all very passionate regarding involving people who are doing the value-added work in order to improve the process, but this dimension is not sufficiently comprehensive to define a Toyota leader. The second dimension of the matrix requires that the leader should also have a profound understanding of the work.



**Figure 2-17: Toyota leadership model**  
(Liker 2004:181)

In the matrix above, four different leaders are described. The least effective one is the top-down manager who typically has a limited understanding of the work and only uses his management expertise. This management style defines in a bureaucratic manager. Such a manager cannot be successful, since he is trying to run the organisation, commanding and controlling it, without truly understanding what is going on. The only option that he has is to make rules and policies and to measure the employee performance according to these. "This leads to metric-driven management that takes the focus away from satisfying customers or building a learning organisation" (Liker, 2004:181).

A bottom-up leader who wants to develop people but does not really understand the work is called a 'group facilitator'. According to Liker (2004:181), such leaders are catalysts, but they cannot teach or guide people on the content of their work, because they do not understand the work. With their lack of experience, they cannot even judge between excellent work and poor performance.

A 'task master', on the other hand, is a manager who is an expert in his area, but has a top-down approach and lacks people skills. He treats employees as puppets. This is very dangerous, since one wrong pull of a string can cause everything to collapse. According to Liker (2004:182),

this leader is distrustful of others with less experience. He would meter out orders, but these will contain precise instructions on how to perform the job. He is the personification of micro-manager.

In contrast, a Toyota leader needs to have the combination of experience and the ability to develop, mentor and lead people: “They are respected for their technical knowledge and are followed for their leadership abilities” (Liker, 2004:182). Toyota leaders seldom give orders; they rather lead and mentor through questioning. They will ask questions about the situation and the employee’s planned approach, but they will not provide answers - even if they have all the knowledge.

In the matrix, the Toyota leaders are shown in all four quadrants because each of these leadership forms have a role at the appropriate times and situations: “The roots of Toyota leadership, goes back to the Toyoda family who developed Toyota Way principle 9: *Grow leaders who thoroughly understand the work, live the philosophy and teach others*” Liker (2004:183).

According to Liker (2004:182) a common phrase heard around Toyota is: “Before we build cars, we build people”. The real challenge facing leaders is to have the long-term vision of knowledge regarding what to do, the knowledge needed in terms of how to do it, and the ability to develop people so that they can understand and do their job excellently. This approach is the foundation of true long-term success.

### **Principle 10: Develop exceptional people and teams who follow the company’s philosophy**

According to Liker (2004:185), everyone at Toyota knows the importance of team work. All systems are put in place with a view to support a team who performs value-adding work. “But teams do not do value added work, individuals do” (Liker, 2004:185). Teams can coordinate the work, motivate each other, and learn from each other. Additionally, they can suggest innovative ideas and they can even control through peer pressure. However, individuals are much more effective in doing the detail work required.

“Toyota has established an excellent balance between individual work and group work and between individual excellence and team effectiveness” (Liker, 2004:186). The notion of team work is not used to compensate for a lack of individual skills or understanding of the TPS. Individual performers are required to make up teams that excel. Toyota therefore invests a great deal of

effort to screen prospective employees. They send out a message that the capabilities and the characteristics of the employee matters. At Toyota years are spent grooming individuals in order to develop depth of technical knowledge, a broad range of skills and a second-nature understanding of Toyota's philosophy.

According to the book *The One Minute Manager Builds High Performance Teams* (Blanchard, Carew and Parisi-Carew, 2000), groups have to develop over time, and successful groups do not emerge from a bunch of individuals to a high performing team in a short space of time. Ken Blanchard (2000) describes four stages of team development:

**Stage 1: Orientation** – During this stage the group needs strong direction from the leader. They must understand the basic mission, rules of engagement and tools that the team will be using.

**Stage 2: Dissatisfaction** – The previous stage was much concerned with planning and talking about great visions and success. The group now realises that the process is harder than they thought and not as much fun as originally anticipated. However, they still need strong leadership and structure as well as social support in order to get through the tough social dynamics that they do not yet understand.

**Stage 3: Integration** – The challenge for the team is to learn about roles, goals, norms and team structure. They begin to develop a clearer picture of the role of each member and start to exert control over team processes. They do not need as much task direction, but they still need social support.

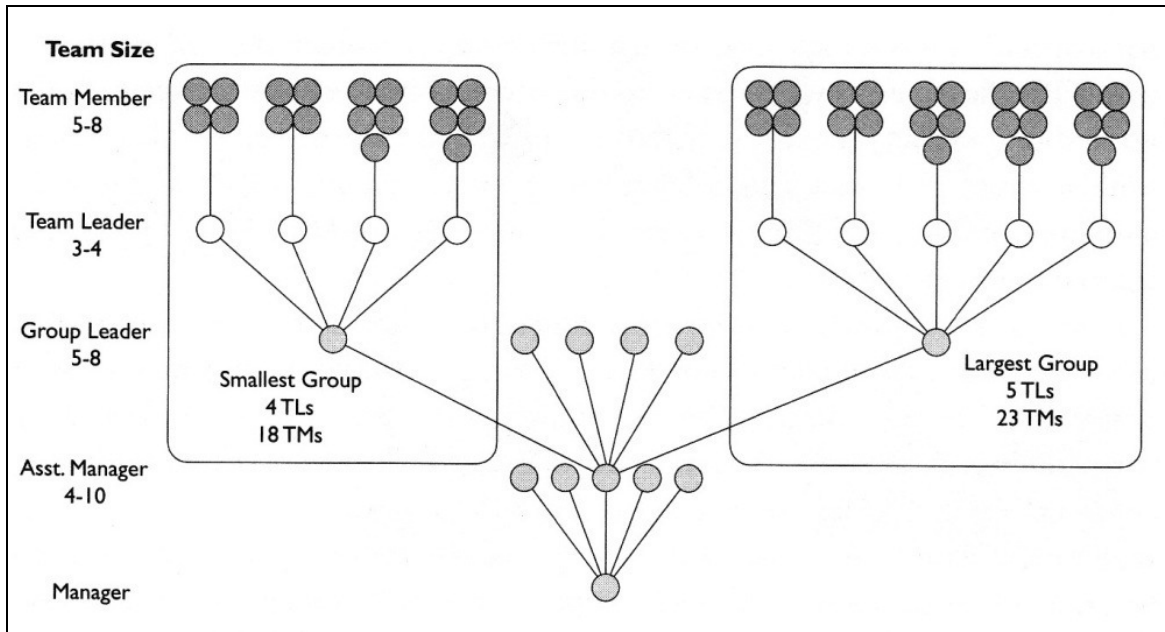
**Stage 4: Production** – The group brings everything together as a high performing team that requires little task support or social support from the leader.

This model is referred to as *situational leadership*. According to Liker (2004:189), Toyota combined this model with TPS into a something much more powerful. Blanchard *et al.* (2000) focus on people having meetings. Toyota was building work teams that did finely tuned value-adding work every day, as well as making improvements to the work that proves them as problem-solving groups. What Toyota did is much more than task force meetings. This led to something that could not be taught in 'one minute'. Each stage could actually take years.

When using traditional batch-and-queue manufacturing, workers are oblivious to any problems occurring upstream or downstream. Inventory is built up between workers and when any defects occur, they simply take another part out of the pile of inventory. On the other hand Liker (2004:189) suggests that, when it is decided that everyone must become one team and the brainstorming starts, everyone will tend to concentrate on how to reduce the time spent on value-added processes, the work they perform or on creature comforts such as water coolers and better lighting. In a batch-and-queue process, workers work individually, and therefore it seems naturally for them to focus only on their individual tasks. However, when one-piece flow is introduced, the team is forced to work together - otherwise there will be no flow and, ultimately, no product.

According to Liker (2004:191), the difference between the one-minute version of situational leadership and the Toyota version is that the latter believe in holding meetings with action items and actually working as a team in a tightly coordinated work system: "The individuals in the coordinated system are executing standard operating procedures and there is a need for tight synchronisation across associates to get the job done right, this type of teambuilding does not happen in a conference room across well fashioned meetings" (Liker, 2004:189).

White-collar or skilled-trained staff usually have the responsibility of problem-solving, quality assurance, equipment maintenance and productivity. According to Liker (2004:195), at Toyota the opposite is true; the shop floor work groups are the focal point for problem solving. Toyota's reason for being is to add value for its customers and it is the team members who do the actual value-adding work. Therefore, the team members are put at the top of the hierarchy and the rest are there to support them. The next line on the hierarchy is made up of the team leaders who have worked the line and have the opportunity to aspire towards a small promotion. They cannot take disciplinary action but are there to support the team members. The first-line supervisor is the group leader, who is responsible for leading and coordinating a number of groups.



**Figure 2-18: Typical Toyota organisation**  
(Liker, 2004:192)

Conventional organisations may glance at a Toyota structure and believe it to be very ineffective, since there are numerous leaders for small groups of people, especially knowing that it is not often the case that the team leaders are doing production work. Traditional organisations do not understand the Toyota organisational structure, because in their organisations the bottom-up management approach is a cliché to the extent that it is barely ever questioned.

At Toyota, the waste is continually removed and the inventory lowered. Traditional job layouts are designed with waste built in. According to Liker (2004:192), this waste is a cushion from the perspective of the workers. When this waste is removed and replaced with additional value-adding tasks, the worker needs to be on his toes: “This would arguable be inhumane if it were not for the team leader system. The team leader is like an on-the-spot physician ready to jump in any time there is a problem, such as when there is a call for help through the *andon* system. The team leader is also a safety valve, walking the line and watching to see if there are any problems emerging, such as parts getting low or someone getting behind who needs assistance or relief” (Liker, 2004:192).

According to Liker (2004:192), the roles and responsibilities of team members, Team Leaders and Group Leaders are divided as follows:

#### Team members

- Perform work to current standard;
- Maintain the 5Ss in their work place;
- Perform routine minor maintenance;
- Look for continuous improvement opportunities; and
- Support problem-solving small-group activities.

#### Team leaders

- Process start-up and control;
- Meet production goals;
- Respond to *andon* calls by team members;
- Confirm quality – perform routine checks;
- Cover absenteeism;
- Responsible training and cross-training;
- Work orders for quick maintenance;
- Ensure that standardised processes are followed;
- Facilitate small group activities;
- Ongoing continuous improvement projects; and
- Ensure that parts/materials are supplied to process.

#### Group leaders

- Handle manpower / vacation scheduling;
- Responsible for monthly production planning;
- Administrative duties such as policy, attendance and corrective actions;
- *Hoshin* planning;
- Team morale;
- Confirm routine quality and team leader checks;
- Shift-to-shift coordination;
- Process trails (change in process);
- Team member development and cross-training;

- Report / track daily production results;
- Cost reduction activities;
- Process improvements projects: productivity, quality, ergonomics and the like;
- Coordinate major maintenance efforts;
- Coordinate support from outside groups;
- Coordinate work with up-stream and down-stream processes;
- Group safety performance;
- Help to cover for the team leader in the case of absence; and
- Coordinate activities around major model changes.

According to Liker (2004:194), when one is employed by Toyota, there is always an immediate mentor to give support on a daily basis. Nobody is left in the cold to figure out solutions and the like for themselves. At Toyota, the mentorship style is based on giving challenging assignments and letting novice struggle until they pull the *andon* and call for help.

At Toyota employees are not simply supported, they are also motivated. According to Liker (2004:196), Toyota uses the following motivation theories:

- Maslow's need hierarchy

When people's basic needs are satisfied they are motivated. Higher levels of motivation consist out of reinforcing self-esteem (feeling good about oneself) and self-actualisation (doing things that improve oneself as a person). Humans can, however, only work on higher-level needs when their lower-level needs are satisfied, for example physiological needs (having enough to eat), safety and security (feeling safe from harm) and social approval (feeling that one is accepted by people that one cares about).

- Herzberg's job enrichment theory

The absence of fulfilment of lower level needs will cause dissatisfaction, but it is also true that providing a person with more and more of these will not motivate him/her in a positive way. If one really wants to motivate people, one has to go beyond basic needs and enrich jobs so that the employees are "intrinsically" motivating. People who perform tasks therefore need feedback on how they are doing. They need to perform an entire piece of work so that they can identify with the product of their work. Furthermore, they also need a degree of independence.

- Taylor's scientific management

Taylorism is the ultimate form of external motivation. This view holds that people only come to work to make money. It follows that one motivates employees by providing them with clear standards, teaching them the most effective way to achieve these standards, and then giving them bonuses when they exceed the standards. These standards, however, needs to be set in terms of quantity, not quality.

- Behaviour modification

This approach entails that rewards and punishments are used to motivate employees. There are many things that people find rewarding and punishing, that is not connected to money. Examples are praise from a supervisor or winning an award. It is important that the positive or negative reinforcement comes as quickly as possible after the action has been completed.

- Goal-setting

People are motivated by challenging, but attainable goals. They need to be measured according to their progress towards these goals.

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

According to Liker (2004:199), automotive industry suppliers consistently report that Toyota is their best customer – and also their toughest. In this case toughest does not mean difficult to get along with; it simply refers to Toyota having high standards of excellence and that they consequently expect all their partners to comply with these standards. The important thing is that they help their partners grow to these standards.

When Toyota became a global powerhouse, they maintained to the basic principles of partnership. They reviewed new suppliers very carefully and only gave them small orders. Suppliers had to pass the test of being trustworthy and dependable. They had to show their commitment to Toyota's high performance standards for quality, cost and delivery. After they had showed this, their orders would increase. Toyota would then teach them the Toyota Way and adopt them into the family. Once a supplier is part of the family, they will not be kicked out except for the most egregious behaviour. Toyota will never jump from supplier to supplier for seemingly better pricing or service.

Having respect for the extended network of supplier partners does not mean that Toyota is 'soft' and an easy target. In the same way that Toyota challenges its own people to improve, it also challenges its suppliers. They do this by setting aggressive targets and challenges to meet those stretch targets. According to Liker (2004:202), suppliers want to work for Toyota because they know they will get better and develop respect among their peers and customers. They are also aware of the fact that Toyota is not easy to please. For Toyota the definition of respect is to have expectations from their suppliers and then treating them fairly and teaching them. Taiichi Ohno states that (quoted by Liker, 2004:203): "Achievement of business performance by the parent company through bullying suppliers is totally alien to the spirit of the Toyota Production System".

According to Liker (2004:201), Toyota has honed their skills in applying TPS by working on projects with suppliers. They need their suppliers to be as capable as Toyota to build and deliver quality parts just in time. Toyota cannot cut costs if their suppliers do not cut costs and forcing cost reductions is simply not part of the Toyota Way.

Toyota uses many methods to learn with its suppliers. By following the Toyota Way, all of these methods are learning-by-doing processes that keep classroom-training to a minimum. All key Toyota suppliers are part of Toyota's supplier association. They are core Toyota suppliers that meet throughout the year to share practices, information, and concerns. There are committees that work on specific things such as joint ventures. Members of Toyota's supplier association can participate in many activities including study groups that meet to develop greater skills in TPS. These are called *jishuken* or voluntary study groups.

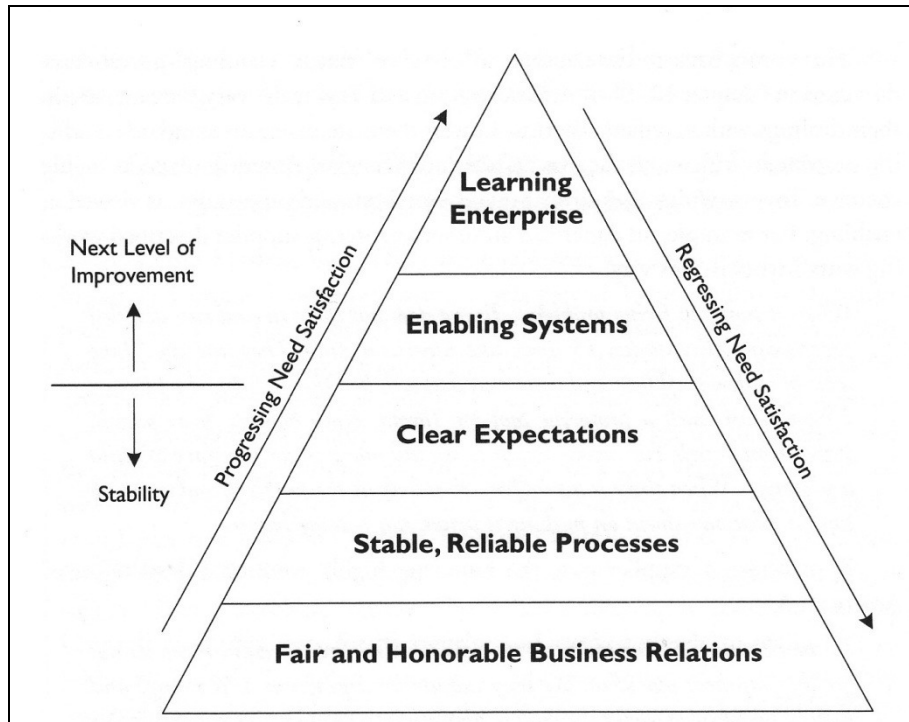
*Jishuken* was initiated in 1977 in Japan by the Operations Management Consulting Division (OMCD). OMCD is the elite corps of TPS experts started by Ohno in 1968 aimed at improving operations in Toyota and its suppliers (Liker, 2004:210). They rotate across companies, working on three to four month projects in companies on a one-by-one basis. The projects involve radical transformation, not incremental improvements. They often tear up the floor, creating one-piece flow, levelling the schedule and so forth in order to bring about significant improvements in cost quality and delivery. Strict targets are set and achieved.

Even Toyota's purchasing department has its own quality and TPS experts who work with suppliers when problems occur (Liker, 2004:212). The most severe problem that a supplier can cause is to shut down the Toyota plant due to a quality or production problem. To prevent this

from happening, they have developed a system that is used to evaluate and classify suppliers. Suppliers are rated from 1 (in the case where a plant burns down, for example) to five (an exemplary TPS supplier). If a supplier puts Toyota in danger of shutting down, it will be rated as a two and Toyota will send a team of people through the supplier's plant. The supplier will have to come up with an action plan with a view to address all their concerns. This team is called the "supplier improvement committee". Additionally, the supplier is put on probation for a year. Toyota names these suppliers the "sick supplier club".

In order to help suppliers, Toyota gives them wide-spread support; from technical issues to human resource audits, because they have realised that the problem runs much deeper than the quality of the process or the tooling of the process. Its causes were rather found in the human dimension. Toyota would then perform a very profound analysis of the organisation. They would look at the turnover ratio, what they paid their employees; and how they decided what the pay scale should be in an area. They investigate the training, development, determine whether the supplier conducts an opinion survey, and so forth. HR would perform the HR investigation, quality would undertake the quality audit and the production engineer would examine the manufacturing side.

Liker (2004:215) also addresses Maslow's needs hierarchy (which suggests that humans can only work on higher-level needs like self-actualisation, once their lower-level needs are satisfied) and developed a supplier version of it (Figure 2-19). "Figure 2-19 suggests that until the relationship has stabilised to the point where business relationship is fair, processes are stable and expectations are clear, it is impossible to get to the higher levels of enabling systems and truly learning together as an enterprise. And you can come down the hierarchy as fast as you can go up" (Liker, 2004:216). "What cements Toyota as the model for suppliers is its approach to learning and growing together with its suppliers. It has achieved in my view, something unique: an extended learning enterprise. This is, to me, the highest form of the Lean enterprise" (Liker, 2004:217).



**Figure 2-19: Supplier chain need hierarchy (modelled after Maslow's need hierarchy)**  
 Liker (2004:215)

In conclusion, the organisation should have respect for their partners and suppliers and they should treat them as an extension of the business. By challenging their outside business partners to grow and develop, it is clear that Toyota values them.

#### 2.2.5.4. Problem-solving – Continuously solving root problems drives organisational learning

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

##### ***(Genchi Genbutsu)***

The one thing that distinguishes the Toyota Way from other management approaches is the principle of *genchi genbutsu*. (Liker, 2004:223). This entails that one cannot fully understand a problem unless one goes and sees for oneself, firsthand. It is unacceptable to take anything for granted or to rely on the reports of others. What one sees firsthand will not show up in reports and tables and numbers. Reports are also necessary, but these only show results. Reports do not reveal the detail of the actual process being followed every day. In order to understand and resolve the problem, one needs to know and understand the process, not just the results.

According to Liker (2004:224), *genchi* is translated as “location” and *genbutsu* as “actual materials or products”. However, *genchi genbutsu* is translated and interpreted in the Toyota Way as “going to the place to see the actual situation for understanding”. The first step of any problem-solving process, evaluation of an employee’s performance, or the development of a new product entails grasping the actual situation. This requires one to go and see for oneself. Toyota promotes creative thinking and innovation, but the foundation of this should be to thoroughly understand all aspects of the situation. This behaviour is what distinguishes someone trained in Toyota from others. No one takes anything for granted and they know what they are talking about, because it comes from firsthand knowledge.

“*Data is of course important in manufacturing, but I place the greatest emphasis on facts*”. Tachii Ohno (quoted by Liker, 2004: 226). It may be easy to instruct all managers to spend half an hour a day on the production floor, observing activities in order to understand the situation. However, this would accomplish very little unless these managers had the skills required to analyse and understand the current situation (Liker, 2004:224). There is a surface version of *genchi genbutsu* and there is also a much deeper version that takes employees many years to master.

The Toyota Way requires that the employee is able to:

- “Deeply” understand the process of flow, standardised work, etc.;
- Have the ability to critically evaluate and analyse what is going on (this may include analysis of data); and
- Know how to get to the root cause of any problems they observe and communicate it effectively to others.

When a problem needs to be solved, the following principles should be kept in mind (Liker, 2004:225):

1. Think and speak based on verified, proven information and data. This means:
  - Go and confirm the facts for oneself; and
  - One is responsible for the information that one reports to others.
2. Take full advantage of the wisdom and experience of others to send, gather or discuss information.

According to Liker (2004:234), the first reaction of U.S. managers is often that this approach is another form of micro-management, but that was only until they began to practice it and experience the benefits thereof.

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

“If you’ve got a process that is supposed to be fully implemented in a year, it seems that most American companies will spend about three months on planning and then they’ll begin to implement. They will then encounter all sorts of problems after implementation, and they will spend the rest of the year correcting them. However, given the same year-long project, Toyota will spend 9 to 10 months planning, then implement at the end of the year, with virtually no remaining problems” (Alex Warren, former senior vice president, Toyota Motors Manufacturing Kentucky, quoted by Liker, 2004:237).

For Toyota, how one arrive at a decision is just as important as the quality of the decision. It is mandatory to take the time to do it right. Management will forgive a decision that does not work out as expected, if the process followed was the right one. A decision that works out well by

chance, but which was based on a shortcut process, is more likely to lead to a reprimand from the boss (Liker, 2004:238).

According to Liker (2004:239), Toyota's thorough consideration during decision-making processes includes five major steps:

1. Finding what is really going on, including *genchi genbutsu*.
2. Understanding underlying causes that explain surface appearances – asking “why” five times.
3. Broadly considering alternative solutions and developing a detailed rationale for the preferred solution.
4. Building consensus within the team, including Toyota employees and outside partners.
5. Using very efficient communication vehicles to do 1-4, preferably using only one side of one sheet of paper.

*Genchi genbutsu* was discussed in the previous section. The five-why analysis will be discussed in the next section (Principle 14). This section will focus on steps three to five.

### **Step 3: Broadly consider alternative solutions with a set-based approach**

At Toyota, it will not help to identify the cause of the problem, come up with a brilliant solution and then share it with your mentor. He will ask, which other solutions have been considered and how does the proposed solution compare with these? Toyota's senior engineers are trained to think in sets of alternative solutions. According to Liker (2004:240), they can even think concurrently about how things such as the design of the product and the manufacturing system fit together. This is called “set-based concurrent engineering”.

When one solution is considered, developed and refined through iteration, it is called a “point-based process”. By applying this notion, the engineer might have completely missed a much better alternative. By spending 80% of the allocated time on planning, time is used to consider a broad range of alternatives before deciding on the most appropriate one. The advantage of getting many opinions from many different people is that many alternatives are brought to light that can then be systematically evaluated.

#### Step 4: Getting on the same page through *nemawashi*

Principle 13 includes the process of *nemawashi* (making decisions slowly by consensus, thoroughly considering all options; implementing rapidly). People build consensus by developing a proposal and circulating it broadly for management approval. Many people have the opportunity to provide their input and this generates consensus. By the time the proposal needs to be approved by high-level management, the decision has already been made, because agreements have already been reached and the final meeting is simply a formality.

According to Liker (2004:242), a variety of decision-making techniques is used at Toyota for different situations. The methods range from a manager making a decision unilaterally and announcing it to the group for consensus with full authority to implement the decision as they agree to. As seen in Figure 2-20, the preferred approach at Toyota is group consensus, but with management approval. However, management reserves the right to seek group input and then make a decision and announce it. This is done only if the group is struggling to achieve consensus and management must step in, or if there is an urgent decision to be made. The philosophy is to seek the maximum involvement appropriate for each situation.

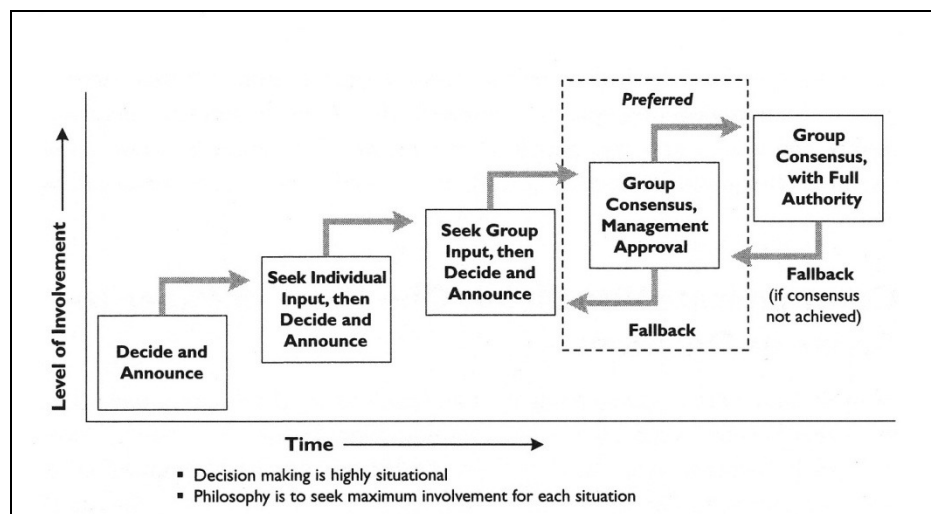


Figure 2-20: Alternative Toyota decision-making methods  
Liker (2004:243)

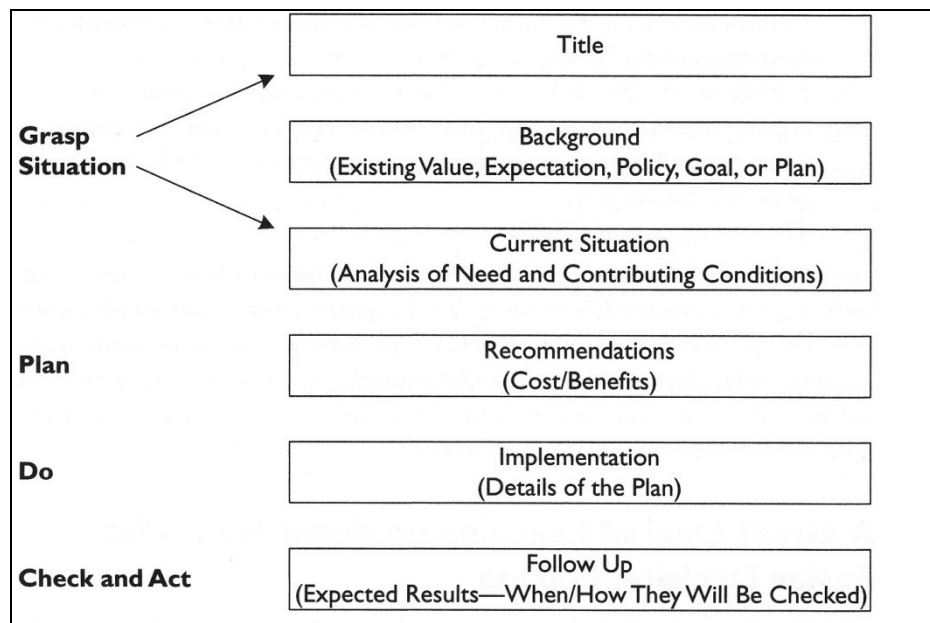
#### Step 5: Communicate visually on a piece of paper to achieve decisions

In order to achieve consensus, communication is directed back and forth. One might therefore be led to believe that Toyota takes forever to get anything done. This is not the case, however, since they have developed the notion of communication into a science. The most difficult and time-consuming way to understand a complex idea is to have to decipher a lengthy report filled with

technical data, business terminology and tables of data. According to Liker (2004:244), the visual approach is much more efficient, because a picture is worth a thousand words. The A3 report is a key part of the process of efficiently getting consensus on complex decisions. According to Liker (2004:157), the A3 would briefly state the following:

- Problem
- Current situation
- Root cause
- Alternative solutions
- Recommended solution
  - Plan
  - Implementation process
  - Timeline
- Cost-benefit analysis.

All of the information would be on one piece of paper using figures and graphics as much as possible. Embedded in the A3 report is Toyota's problem-solving process which is based on the Deming Cycle. According to Liker (2004:246) this process includes the elements of planning, doing, checking and acting.



**Figure 2-21: Plan-Do-Check-Act in the proposal process**  
Liker (2004:247)

Figure 2-21 shows how the A3 report incorporates PDCA. With *genchi genbutsu* in mind, the A3 reports starts with one step before planning – a thorough understanding of the current situation, the values, expectations, policies, reasons for the current system, and so forth. Once this groundwork has been completed, the Deming Cycle steps are followed: The planning, doing or implementing the plan, then checking and acting.

One of the benefits of the A3 communication format and a disciplined approach to problem solving is that Toyota runs its meeting very efficiently. According to Liker (2004:247), the discipline of the A3 process helps to accomplish effective meetings. There are several prerequisites to an efficient meeting:

1. *Clear objectives prior to the meeting* – These are sometime reflected in an agenda, but the agenda needs to be very focused on the clear tasks and deliverable.
2. *The right people at the meeting* – People expected to show up need to show up.
3. *Prepared participants* – All participants know what they should prepare for the meeting and must have done so.
4. *Effective use of visual aids* – The A3 format is extremely effective.
5. *Separate information sharing from problem solving* – Share as much as possible information prior to the meeting so that the focus of the meeting can be on problem-solving.
6. *The meeting starts and ends on time.*

According to Liker (2004:248), the lengthy and thorough information gathering analysis applied during the decision-making process, helps Toyota to achieve the following:

1. It helps to broaden the search for solutions;
2. Execution tends to run flawlessly, because all the facts that could lead to problems later, have already been considered beforehand;
3. Once a decision has been made, it is easy to implement because everyone has already agreed to it; and
4. The process allows for a great deal of learning upfront, before anything is even planned or implemented.

**Principle 14: Become a learning organisation through relentless reflection (*hansei*) and continuous improvement (*kaizen*)**

“Long gone are the days when a company could set up shop, make a product well and then milk that product for years, hanging on to its original competitive advantage. Adaptation, innovation and flexibility have knocked this old business approach off its pedestal and have become the necessary ingredients for survival as well as the hallmarks of a successful business. To sustain such organisational behaviour requires one essential attribute: the ability to learn. It must become a *learning organisation*” (Liker, 2004:250).

A learning organisation does not only learn new business or technical skills; it also learns how to learn new skills, capabilities and knowledge. In order to adapt to a continually changing environment, the learning capacity of the organisation should develop and grow over time. According to Liker (2004:250), Toyota is the best learning organisation, because they see standardisation and innovation as two sides of the same coin. The foundation of the Toyota Way of learning is standardisation that is interrupted by innovation, which is then translated into new standards.

The Toyota Way involves the following:

1. Learning from one's mistakes;
2. Determining the root cause of the problems;
3. Providing effective countermeasures;
4. Empowering people to implement those measures; and
5. Having a process to transfer the new knowledge to the right people with a view to make it part of the company's repertoire of understanding and behaviour.

According to Liker (2004:252), continuous improvement is only possible when a process is stable and standardised. An organisation can only learn from its improvements once a process is in place to make waste and inefficiencies public. To be a learning organisation it is necessary to have:

- Stability of personnel;
- Slow promotions; and
- A very carefully considered succession system to protect the organisational knowledge base.

“To *learn* means to build on your past and move forward incrementally, rather than starting over and reinventing the wheel with new personnel with each project” (Liker, 2004:252). Furthermore, “The core of *kaizen* and learning is an attitude and a way of thinking by all leaders and associates – an attitude of self-reflection and even self-criticism, a burning desire to improve” (Liker, 2004:252). Westerners view tend to criticise and admitting to a mistake as something negative and a sign of weakness. This is the opposite of the Toyota Way. According to Liker (2004:252), the greatest sign of strength is when an individual can openly address things that did not go right, take responsibility and propose countermeasure with a view to prevent these things from happening again.

An integral part of *kaizen* is the five-why analysis. This is used by Toyota in order to determine the root cause of something that went wrong. According to Taiichi Ohno, quoted by Liker (2004:253), true problem-solving requires identifying the root cause instead of simply the source. The root cause lies hidden beneath the source. In order to determine the source, one must dig deeper by asking why the problem occurred. Asking “why?” five times requires taking the answer of the first “why?” and asking why that happened. This will lead one upstream in the process.

5 Whys is a method to pursue the deeper, systematic causes of a problem to find correspondingly deeper countermeasures.

Level of Problem	Corresponding Level of Countermeasure
There is a puddle of oil on the shop floor	Clean up the oil
Why? → Because the machine is leaking oil	Fix the machine
Why? → Because the gasket has deteriorated	Replace the gasket
Why? → Because we bought gaskets made of inferior material	Change gasket specifications
Why? → Because we got a good deal (price) on those gaskets	Change purchasing policies
Why? → Because the purchasing agent gets evaluated on short-term cost savings	Change the evaluation policy for purchasing agents

**Figure 2-22: 5-why investigation questions.**  
Liker (2004:253)

Figure 2-22 provides a hypothetical example of the five-why analysis that Toyota uses in internal problem-solving training.

According to Liker (2004:254), the five-why analysis is used as part of a seven step process Toyota calls “practical problem solving”:

1. The first step is when a large, vague, complicated problem is discovered.
2. Before the five-why analysis can be undertaken, the problem must first be clarified, or in Toyota terms “grasp the situation” (Step 2). This begins with observing the situation and comparing it to the standard. In order to clarify the problem, one must go to where the problem is (*genchi genbutsu*).
3. The third step in the practical problem solving process entails making a first attempt at identifying the point of cause (POC). By asking questions such as “Where is the problem observed?”, or “Where is the likely cause?” will lead one upstream towards the general vicinity of the root cause, which can be discovered by five-why analysis (Step 4).
4. Determine the root cause by means of five-why analysis.
5. The ultimate purpose of the exercise is step 5, which entails implementing a countermeasure.
6. Evaluate the results. Once the results are seen to be effective, these become part of a new standardised approach.
7. Step 7 entails standardising the new process. This proceeds hand in hand with learning and is the basis of continuous improvement. “If you do not standardise the improved process, the learning up to that point falls into a black hole, lost forgotten, and unavailable for further improvements” (Liker, 2004:256).

Even with all these tools, techniques and metrics, Toyota’s emphasis is on thinking through problems and solutions. According to Liker (2004:257), problem solving comprises of 20% tools and 80% thinking.

A key to learning and growing is *hansei*, which is roughly translated as “reflection”. According to Liker (2004:257), team work never overshadows individual accountability. Individual accountability is not used for blaming or punishment, but for learning and growing through *hansei*. *Hansei* is explained as something like a “time-out” for children. When a Japanese child is asked to do the *hansei* it means he/she must be sorry about and improve his/her attitude. Everything is included, spirit as well as attitude.

According to Liker (2004:257), *kaizen* is impossible without *hansei*. In Toyota, when one has done something wrong, one needs to first and foremost feel really sad. Then one set up a future plan

with a view to solve the problem; one must sincerely believe that one will never make this type of mistake again.

*Hansei* is therefore a mindset, an attitude; it is about being honest about one's own weaknesses. When a person is only talking about his/her strengths, he is bragging. In order to recognise one's weaknesses with serenity implies a high level of strength. The process of changing to overcome one's weakness is at the root of the very notion of *kaizen*. *Hansei* and *kaizen* go hand in hand.

After processes have been standardised (Step 7), Toyota measures processes everywhere in the factory according to the following three measures:

1. Global performance measure – How is the company doing?

At this level Toyota uses financial, quality and safety measures.

2. Operational performance – How is the plant or department doing?

According to Liker (2004:260), Toyota's measurements seem to be timelier and better maintained than what he has seen at other companies. They track progress on key metrics and compare them with aggressive targets. These metrics tend to be specific for each process.

3. Stretch improvement metrics – How is the business unit or work group doing?

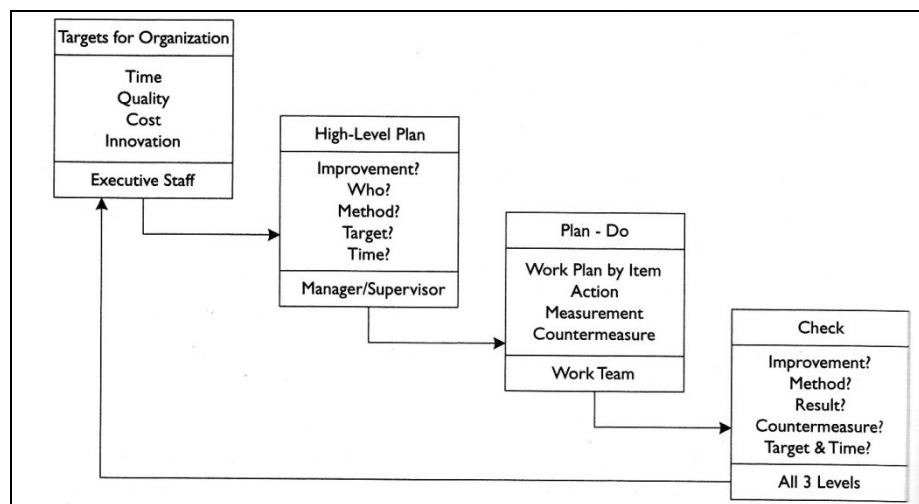
Toyota sets stretch goals for the organisation, which is converted into stretch goals for every business unit, and ultimately, every work group. Tracking progress towards these goals is central to Toyota's learning process.

According to Liker (2004:261), Toyota is process-orientated. Some companies have vital continuous improvement programmes while others have superficial programmes that defuse before they get going. Liker found that companies with vital programmes had process-orientated managers, while unsuccessful companies had results-oriented managers. The results-orientated managers wanted to measure the results of the programme immediately, while the process-orientated managers were more patient and believed that an investment in the people and the process would lead to the results they desired.

To summarise, developing standard, global metrics is not a high priority at Toyota. They approach such a process as simply as possible. They concentrate on being metric-driven, problem-solving and on supporting their process orientation. The most important learning measurements track progress towards stretched improvement goals. This process is called *hoshin kanri*. According to

Liker (2004:262), Toyota managers have become masterful at setting challenging goals with their subordinates and are passionate about measurement and feedback. This is the basis for *hoshin kanri*, (sometimes called “policy deployment”). This is Toyota’s process used for cascading objectives down from the top of the company to the work group level.

The saying that “you get what you measure” is in a sense true at Toyota (Liker, 2004:261). Toyota has realised that the key to organisational learning is to align objectives of all the employees towards a common goal. Simply setting specific, measurable, challenging goals and then measuring progress according to these goals, motivates employees very successfully, even if there is no tangible reward associated with the success. Therefore, aggressive goals start at the executive level and then each level in turn develops measurable objectives for the year which are designed to support the executive-level goals. These objectives must be measurable and very concrete. Vague goal statements are not accepted. Figure 2-23 shows how the process cascades throughout the organisation and follows the PDCA process.



**Figure 2-23: Policy deployment process (*hoshin kanri*)**

Liker 2004:262

When, for example, annual goals are given to a section, it is the section’s responsibility to break the goals down into monthly, weekly and daily goals. Posted performance measures are displayed visually and tracked daily, and no outdated information is tolerated.

The policy deployment measures and actions becomes more specific as one progresses from the senior executives to the working level team members. Progress reports flow upwards from the lower levels to the senior executives. Different methods are used to update senior managers.

They would also go and talk to the workers. Furthermore, there are formal review sessions that are dedicated towards reviewing progress towards the hoshini kanri objectives. The check and act parts of the PDCA are critical to turn the planned goals into effective action.

### 2.2.6. Traditional organisation vs. Lean organisation

Lean is not a quick fix, 5-step plan to success. It is rather a culture that that needs to be adopted by everyone (production, engineering, accounting, finances and the like) in an organisation. Unfortunately, this requires a change in the ways which people view traditional manufacturing and cost concepts.

The differences between traditional and Lean organisations are listed in Table 2-1 below:

**Table 2-1: The differences between traditional and Lean organisations**

<b>Concept</b>	<b>Traditional organisation</b>	<b>Lean organisation</b>
<b>Inventory</b>	Any inventory is seen as an asset by accounting terminology	It is a waste – It ties up capital and increases processing lead times. It utilises valuable floor space
<b>Ideal economic order quantity and batch size</b>	Running large batch sizes to make up for process down time and changes over time	The ideal batch size is one. Continuous efforts are made to reduce downtime to zero
<b>People utilisation</b>	All people must be busy all the time	People might not be busy all the time, because work is performed according to customer demand
<b>Process utilisation</b>	Using high-speed processes and running them all the time	Processes need only be designed to keep up with customer demand.
<b>Work schedule</b>	Building products according to forecasts	Building products according to customer demand
<b>Labor costs</b>	Variable	Fixed
<b>Work groups</b>	Traditional (functional departments)	Cross-functional teams
<b>Quality</b>	Inspecting / sorting work at the end of as process to ensure that all errors are identified	Processes, products and services are designed to eliminate errors

### 2.2.7. Lean myths

Table 2-2 shows the myths around TPS versus the reality (Liker, 2004:297)

**Table 2-2: Myths versus reality of TPS**

<b>Myth:</b> <b>What the Toyota Production System is not</b>	<b>Reality:</b> <b>What the Toyota Production System is</b>
1. A tangible recipe for success 2. A management project of programme 3. A set of tools for implementation 4. A system for production floor only 5. Implementable in the short- or mid-term period	1. A consistent way of thinking 2. A total management philosophy 3. Focus on total customer satisfaction 4. An environment of team work and improvement 5. A never-ending search for a better way 6. Quality-building process 7. Organised, disciplined workplace 8. Evolutionary

### 2.2.8. Overall benefits of implementing Lean

The benefits of implementing Lean can be divided into three categories:

- **Operational improvement** which consists out of:
  - Reduced lead times;
  - Increase productivity;
  - Reduction of work-in-progress;
  - Quality improvement; and
  - Reduction in space utilisation.
  
- **Administrative improvement** which consist out of:
  - Reduction in processing errors;
  - Streamlining of customer service functions so that customers are no longer placed on hold;
  - Reduction in paperwork in office areas;
  - Reduced staff demands, allowing for the same number of office staff to handle larger numbers of orders;

- Documentation and streamlining of processing steps enable the outsourcing of non-critical functions, allowing the company to focus their efforts on customers' needs;
- Reduction of turnover time and the resulting eating-away costs; and
- The implementation of job standards and pre-employment profiling ensures the hiring of only "above average" performers.

- **Strategic improvement**

After decreasing lead times, marketing campaigns are required to increase the sales of a company. This will result in increased revenues, without increased labour or overhead costs. Also, the organisation is able to invoice customers sooner, which improves cash flow.

## **2.3. Six Sigma**

### **2.3.1. Introduction**

Six Sigma is defined in particular terms in the literature as set out below:

*“Six Sigma is a management philosophy focused on eliminating mistakes, waste and rework. It establishes a measurable status to be achieved and embodies a strategic problem-solving method to increase customer satisfaction and dramatically enhance the bottom line. It teaches employees how to improve the way they do business, scientifically and fundamentally, and how to maintain their new performance level. It gives discipline, structure and a foundation for solid decision-making based on simple statistics. It also maximises Return on Investment and Return on Talent” (Chowdhury, 2001:26).*

*“Six Sigma is an improvement strategy to meet or exceed customer needs. It is a structured, disciplined, data-driven process for improving business performance. Six Sigma is used to measure the process capabilities of meeting the customer requirements and determining how far a given process deviates from perfection. Six Sigma tools and methods concentrate on reducing variability in processes” (Rath & Strong, 2003:487).*

The improvement strategy discussed above is referred to as the Six Sigma programme and the measure of process capabilities is referred to as the Six Sigma quality level (Rath & Strong, 2003:487).

The Six Sigma approach suggests that there are two ways to win a game – and points to the second one as the most appropriate:

1. The first is to make spectacular play, like long passes, big runs and great interceptions. This is the sort of things that makes the highlights film.
2. On the other hand, one can also win a game by making fewer mistakes: fewer penalties, fewer fumbles, and fewer interceptions. It may not be as spectacular as the way referred to above, but it is just as important to the bottom line.

Referring to option 1, the team needs spectacular players to make spectacular plays. However, referring to option 2, anyone and everyone can concentrate on making fewer mistakes.

Companies often make the same mistake. They can make more money by coming up with great inventions, hiring stars, or buying other companies. However, good companies also focus on not making mistakes, not wasting time or materials and not making errors in production or service delivery. This means that: "Preventing mistakes can make you just as much money, or more, and anyone can do it." (Chowdhury, 2001:24).

Sigma is the Greek letter that is used to designate a standard deviation, the measure of variation within a process. In the context of Six Sigma, the term is used to indicate the number of mistakes that a company makes. The six represents the sigma level of perfection towards which a company should aim. According to Chowdhury (2001:229), when a company is working at One Sigma, they are making 700,000 defects per million opportunities (DPMO). This implies that at One Sigma one is doing things right 30% of the time. When working at Two Sigma, the company is making a little over 300,000 DPMO. Most companies operate between Three and Four Sigma, which means that they make 67,000 and 6,000 DPMO respectively. When a company is operating at 3.8 Sigma, they are 'getting it right' 99% of the time.

All companies want to improve their quality. They may, however, be under the impression that by simply coming up with a number to achieve perfection will not make that happen. In fact, if one wants to achieve something, one has to know where one stands and where one wants to go; otherwise it will not happen. When one defines these things in anything but numbers, the goal becomes subjective and fuzzy. On the other hand, numbers bring clarity (Chowdhury, 2001:32).

According to Chowdhury (2001:33) if one cannot express what one is trying to say in numbers, one probably does not know what one is talking about. Everything in Six Sigma can be measured, and that is how one determines what to fix and when to fix it, and when one has indeed actually fixed it.

Six Sigma is not simply concerned with improving quality. Improving quality is simply the means to an end. The goal is to ensure customer satisfaction which will add money to the bottom line. If a company is improving quality but the customers are not satisfied, such a company is missing the point of Six Sigma.

According to Chowdhury (2001:33), companies struggle to ensure customer satisfaction because they think that quality costs money. They are of the opinion that it is a trade-off situation between

the customers and the accountants, and that they must calculate how much quality they can afford to give the customer. On the other hand, Six Sigma companies have learned that quality saves money, because it reduces the amount of rework and scrapped parts. It also helps to decrease the amount of warranty payouts and refunds. By achieving all of this, profits are increased. The Quality department and the Finance department of an organisation have to work together, not against each other, because quality helps the bottom line.

Chowdhury (2001:35) propounds that he is amazed at how much money companies spend on attracting new customers and how little they do to keep those customers that they already have. When a company ensures customer satisfaction, they would not need to advertise as much, because word-of-mouth advertising will bring in new customers.

### **2.3.2. Basic Six Sigma concepts**

The basic Six Sigma concepts that will be discussed in this section are the following:

- Variation;
- Type of data; and
- Six Sigma quality.

#### **2.3.2.1. Variation**

"A *process* is referred to as any series of operations performed to bring about a result" (Rath & Strong, 2003:487). Everything that is done to affect the result is part of the process. The result can be the delivering of a service or a product.

"*Variation* is the sum total of all the minuscule changes that occur every time a process is performed and all of the not-so-minuscule changes that occur on occasion" (Rath & Strong, 2003:487). Variation is always present at some level. If this is not the case, the measuring is not done with a fine enough resolution. Variation is the enemy. On the other hand, consistency (and minimal variation) leads to improved quality, reduced cost, higher profits and happier customers.

According to Rath and Strong (2003:488) variation can be divided into the following categories:

- Common-cause variation - Variation that is always present in a process to some degree; and
- Special-cause variation - Variation that is unusual and occurs at a certain time or place.

A *process* should be brought into a state of statistical control in which only common-cause variation is present, because this ensures that process outputs are more predictable and the process can be managed more economically.

A *defect* is any event that does not meet a customer's specification. A *specification* is the limit or set of limits placed on a key, measurable characteristic of importance to the customer, called a Critical-to-Quality requirement.

Sig Sigma refers to no more than 3.4 defects per 1 million opportunities for defects to occur. The objective is to reduce variability. Therefore one needs to quantify the amount of variation first. In order to accomplish this, data is required.

#### **2.3.2.2. The type of data**

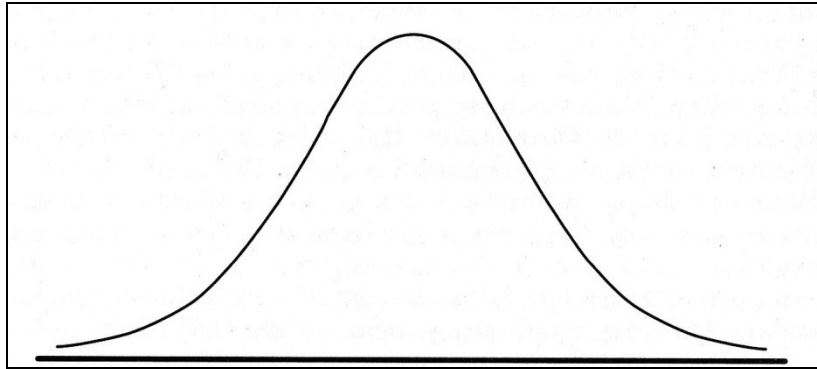
According to Rath and Strong (2003:488), there are two types of data: continuous and discrete. The customer's CTQ requirements can be measured in either of these types of data:

- Continuous data – This type of variable can be broken down into smaller units, such as kilometres into meters into centimetres. Units of continuous variables are, for example, temperature, pressure, thickness, dollars or time.
- Discrete variable – When customer satisfaction is measured as a discrete variable, it is measured as an attribute, for example the service was good or bad, acceptable or unacceptable. There could be an ordered list to choose from (for example poor, fair, good and best). It is measured as a count, a portion or a percentage.

Continuous measures for a CTQ requirement will have a distribution of values that are the result of the variations in the process that produce the product or service. This distribution of values can often be described by a bell-shaped curve (normal curve or normal distribution) as shown in Figure 2-24.

Such a normal curve has certain characteristics:

- It is symmetric on either side of the most frequent occurring value (the peak or mode);
- The peak represents the centre or average of the distribution of values; and
- The value under the curve represents 100% of all the values of the CTQ requirements.

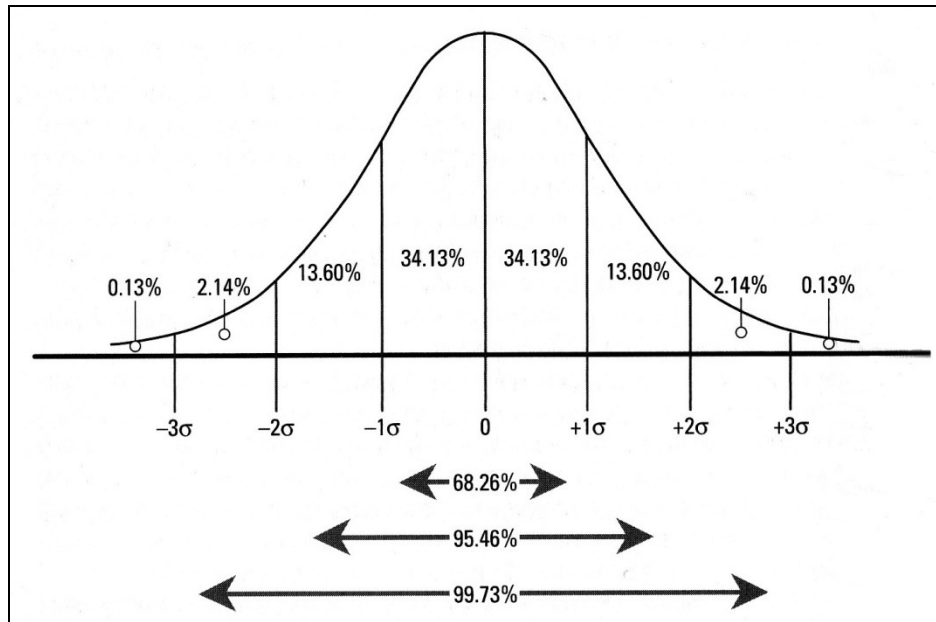


**Figure 2-24: Bell-shaped (normal) curve**  
(Rath & Strong, 2003:489)

A normal curve can be represented by two parameters: the centre (average) and the spread. The average can be calculated by adding all the values together and dividing it by the number of values that were used to constitute the sum. The spread is described by the width of the curve, in other words, the difference between the highest value and the lowest value.

Alternatively, the curve can be expressed by a measure called the standard deviation (Rath & Strong, 2003:489). This is approximately the square root of the average squared deviation from the mean. The width of a normal curve is about six standard deviations. Figure 2-25 shows the percentage of values contained within one, two, and three standard deviations above and below the mean/average.

In Figure 2-25, the Greek letter sigma ( $\sigma$ ) represents the standard deviation. Figure 2-25 shows that 99.73% of all values lie within three standard deviations above or below the centre/average. Therefore the curve is approximately six standard deviations ( $6\sigma$ ) wide.



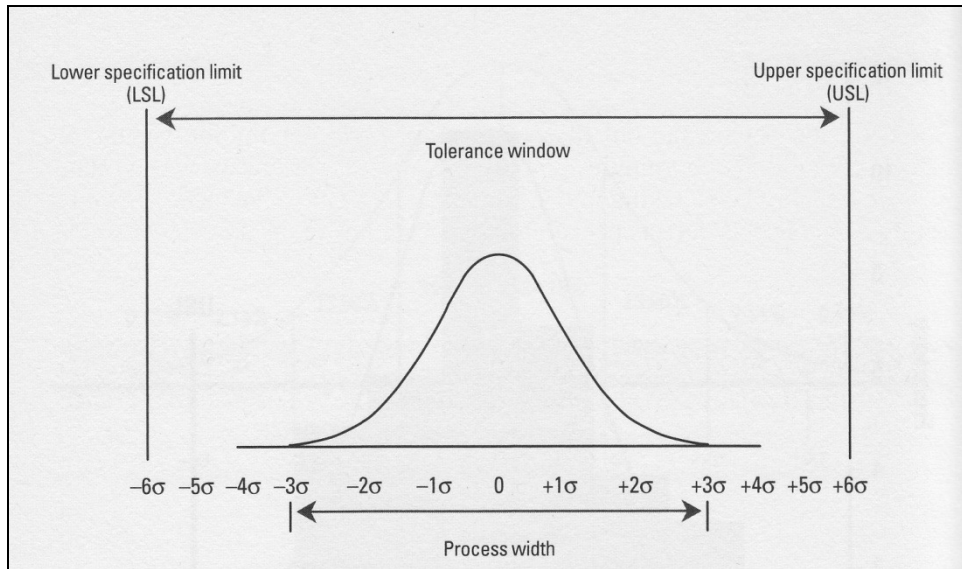
**Figure 2-25: Percentages of values contained within one, two and three standard deviations**  
(Rath & Strong, 2003:489)

Figure 2-25 implies that once a position on the horizontal axis has been determined to be a certain distance (number of standard deviations) above or below the average or mean, statistical tables or software can be used to determine the percentage of the distribution values that fall below or above that position.

In practice, the horizontal axis position is set to a specification for a customer requirement. The percentage of the specification that may currently be produced can then be determined.

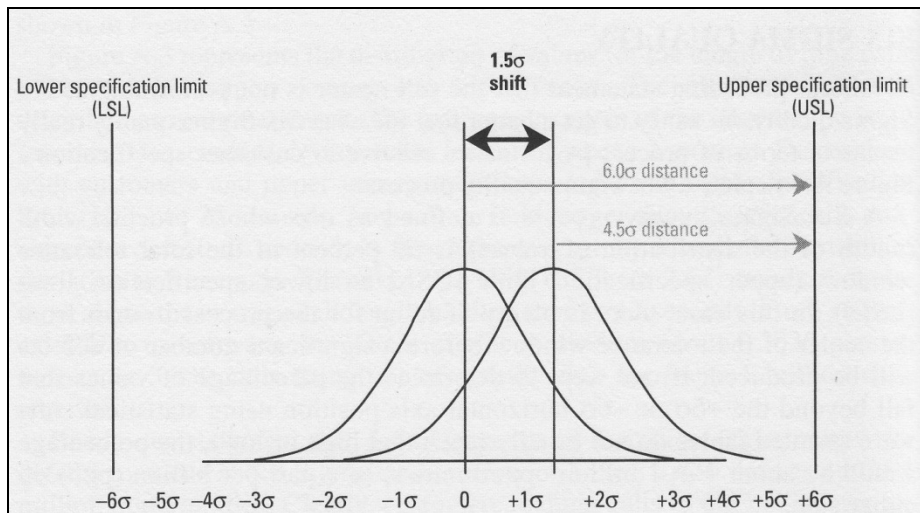
### 2.3.2.3. Six Sigma quality

Figure 2-26 depicts a Six Sigma quality process. Such a process is defined as one where the process width is 50% of the total tolerance window (upper specification limit to lower specification limit). In this case, there is plenty of room for the process to drift from the centre to the tolerance window before a significant number of defects will be produced. If the percentage of values that fall beyond the  $+6\sigma$  or the  $-6\sigma$  horizontal axis positions have been determined using statistical software, the percentage would be about 1 in 1 billion opportunities, or 1 part per billion (ppb) on either side.



**Figure 2-26: Six Sigma quality process**  
(Rath & Strong, 2003:492)

According to Rath and Strong (2003:492), early research showed that processes can drift up to 1.5 standard deviations over time. Early instigators of Six Sigma quality at Motorola decided that if a process were to drift by as much as  $1.5\sigma$ , it should not produce more than 3.4 defects out of 1 million opportunities for defects (3.4 ppm). This has become standard and most tables and software for Six Sigma include the  $1.5\sigma$  shift shown in Figure 2-27.



**Figure 2-27: The 1.5 σ shift**  
(Rath & Strong, 2003:492)

Based on the percentage out of specification, parts per million (ppm) or defects per million opportunities (dpmo) that a process produces, its sigma level can be stated taking into account

the  $1.5\sigma$  shift. The chart shown in Table 2-3 connects defects per million opportunities to the associated sigma scale, assuming a  $1.5\sigma$  shift. It also includes the complement to defects per opportunity: yield percentage.

Table 2-3: Sigma scale table

SIGMA SCALE TABLE (Assumes $\pm 1.5$ Sigma Shift)					
SIGMA	DPMO	YIELD	SIGMA	DPMO	YIELD
6	3.4	99.99966%	3	66,807	93.3%
5.9	5.4	99.99946%	2.9	80,757	91.9%
5.8	8.5	99.99915%	2.8	96,801	90.3%
5.7	13	99.99866%	2.7	115,070	88.5%
5.6	21	99.9979%	2.6	135,666	86.4%
5.5	32	99.9968%	2.5	158,655	84.1%
5.4	48	99.9952%	2.4	184,060	81.6%
5.3	72	99.9928%	2.3	211,855	78.8%
5.2	108	99.9892%	2.2	241,964	75.8%
5.1	159	99.984%	2.1	274,253	72.6%
5	233	99.977%	2	308,538	69.1%
4.9	337	99.966%	1.9	344,578	65.5%
4.8	483	99.952%	1.8	382,089	61.8%
4.7	687	99.931%	1.7	420,740	57.9%
4.6	968	99.90%	1.6	460,172	54.0%
4.5	1,350	99.87%	1.5	500,000	50.0%
4.4	1,866	99.81%	1.4	539,828	46.0%
4.3	2,555	99.74%	1.3	579,260	42.1%
4.2	3,467	99.65%	1.2	617,911	38.2%
4.1	4,661	99.53%	1.1	655,422	34.5%
4	6,210	99.38%	1	691,462	30.9%
3.9	8,198	99.18%	0.9	725,747	27.4%
3.8	10,724	98.9%	0.8	758,036	24.2%
3.7	13,903	98.6%	0.7	788,145	21.2%
3.6	17,864	98.2%	0.6	815,940	18.4%
3.5	22,750	97.7%	0.5	841,345	15.9%
3.4	28,716	97.1%	0.4	864,334	13.6%
3.3	35,930	96.4%	0.3	884,930	11.5%
3.2	44,565	95.5%	0.2	903,199	9.7%
3.1	54,799	94.5%	0.1	919,243	8.1%

### **2.3.3. Six Sigma methodology (DMAIC)**

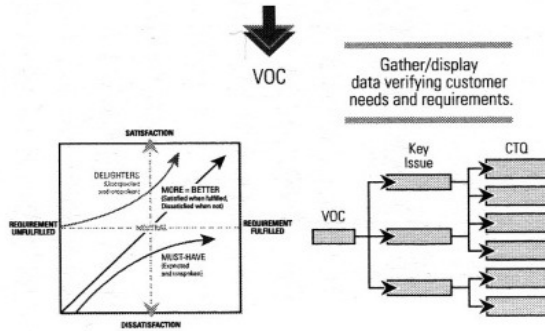
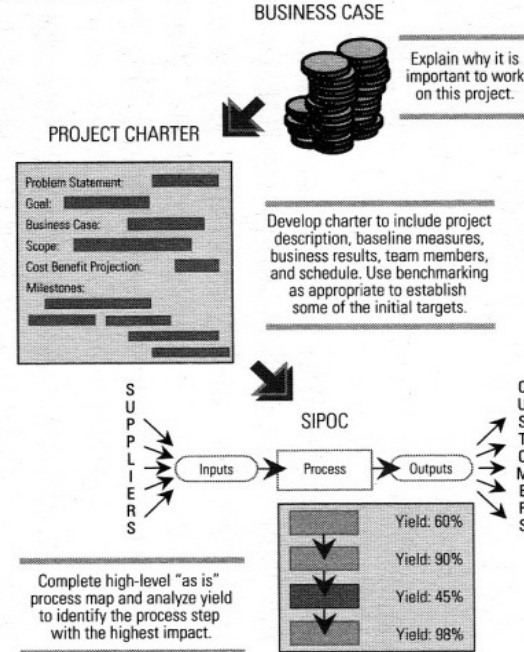
Six Sigma uses a methodology called DMAIC (Define – Measure – Analysis – Improve – Control) when implementing continuous improvement projects (Britz, 2008:21) This approach is followed for each project from beginning to end, regardless of whether it involves a manufacturing process, an administrative process, or a support process. “DMAIC process is an improvement methodology for existing processes falling below specification where incremental improvement can bring the process into conformance to Six Sigma quality levels” (Rath & Strong, 2003:495). Figure 2-29 shows the DMAIC process graphically.

# The Six Sigma/ DMAIC Road Map



**DMAIC** is a rigorous process improvement methodology to achieve the stretch goal of Six Sigma or 3.4 defects per million opportunities. It is a structured and disciplined approach in five logically linked phases: define, measure, analyze, improve, and control. DMAIC integrates the Voice of the Customer and the customer's Critical-to-Quality requirements into the improvement process.

## Define



## Measure

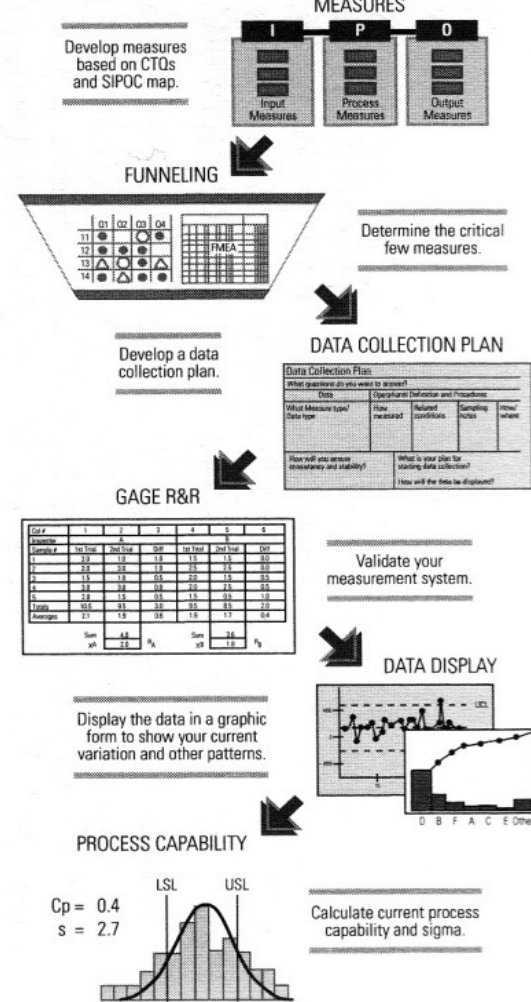


Figure 2-28: DMAIC methodology (continue on next page)  
(Rath & Strong. 2003:198)

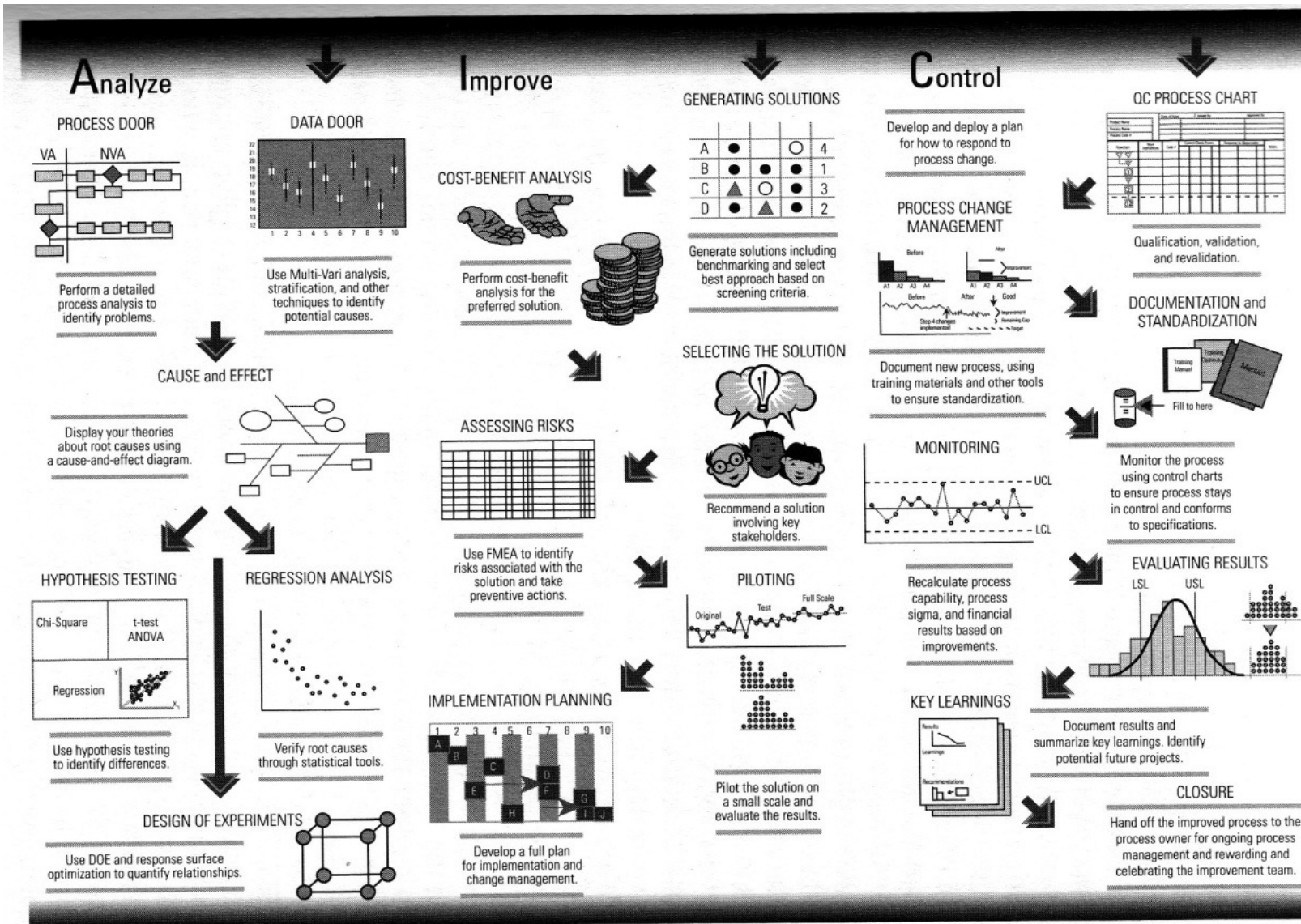


Figure 2-29: DMAIC methodology (continue from previous page)  
(Rath & Strong. 2003:198)

“DMAIC is a rigorous and proven problem-solving approach that includes both a set of tools and a sequence of applying those tools. It is a data-driven approach to improving processes in a logical and methodical way” (Rath & Strong, 2003:196). Throughout Six Sigma projects, phrases such as “We feel that...” or “We suspect that...” are not allowed. Instead phrases such as “The data shows that...” and “Statistical analysis of the data supports that...” should be used. This emphasis on data has made Six Sigma so successful (Brits, 2008:21).

Before the DMAIC methodology can be followed, a project needs to be selected. This selection is a leadership responsibility, not the responsibility of the team. It is the business leader’s responsibility to assign the process to be improved and to establish the focus of the improvement effort, as well as the initial scope and the expected benefits. As the team progresses through the project and develops a clearer understanding of the problem, they can be expected to update the original scope and deliverables. These updates are submitted to the leadership team for approval. (Rath & Strong, 2003:197).

#### **2.3.3.1. Define phase**

The purpose of the define phase is to determine the project focus: what the expected business benefits are, and what resources are required to complete the effort (Rath & Strong, 2003:197).

At the onset of any project, the team clearly identifies the suppliers, process inputs, process activities, process outputs and the customers. They establish the baselines and benchmarks. Goals and measure of success are set (Rudisilli & Clary as quoted by Britz, 2008:21).

The foundations for the project are also laid. A business case is developed in order to ensure that there is a valid reason for expending the time and resources required to work through the problem-solving methodology (Rath & Strong, 2003:200).

The tools used in the define phase are the following (Rath & Strong, 2003:201) (Annexure 2 provides a brief description of each 'tool'):

- **Project Charter** - A contract between the improvement team and the management that identifies the current situation with a problem statement and goals that are agreed upon.
- **SIPOC** - Working from the team charter, the team identifies the business process that is responsible for the problem and creates a SIPOC map, a high-level map used to identify the suppliers, inputs, process steps, outputs and customers (Rath & Strong, 2003:200).
- **Stakeholder Analysis** - Since the DMAIC project will require fundamental changes to the process, it is also crucial to identify the stakeholders early on and to develop appropriate communication plans. Typical stakeholders are managers, people who work in the process, upstream and downstream department, customers, suppliers and finance.
- **VOC Analysis** – The team must identify those customer requirements used to evaluate the process output. This data is collected from several sources, both reactive (existing data on complaints, service calls or returns) and proactive (surveys, one-on-one meetings or focus groups) the level of sophistication used in collecting this data should correspond to the complexity of the problem and the potential payoff of its solution.
- **Affinity Diagram** – The team organises and analyses the VOC data. An affinity diagram is used to identify the common issues or trends in the set of customer comments. An affinity diagram is a tool used for organising discrete customer comments into a comprehensive picture of customer needs. Once organised, these comments can be translated from the customer's language into the language of the process.
- **CTQ Tree** – The customers' comments are used to identify the Critical-to-Quality requirements (CTQ's). A CTQ tree supports this task.

At the end of the define phase the team should meet with the sponsor or champion and discuss its progress up to this point – a *Tollgate review* is held at this point. The sponsor is expected to review the work of the team and to ensure that they are still on track. Tollgate reviews at each phase are critical to ensure that the organisation is kept informed of progress, knows exactly what the team is doing, and how the project is progressing.

Completion of the define phase ensures the following (Rath & Strong, 2003:201):

- That the problem and the business case are well defined (project charter);
- That the process has been identified (SIPOC);
- That the stakeholders have been identified (stakeholder analysis); and
- That the customer requirements have been established and validated using actual obtained data from the customer (VOC analysis).

### **2.3.3.2. Measurement phase**

A solid foundation has been established during the define phase. During the measurement phase, the team begins the process of understanding all those process variables affecting the process output. The purpose is to collect actual data that will narrow the range of potential causes the team will investigate later in the analyse phase. This will lead to an estimate of how capable the current process is in terms of meeting customer requirements (Rath & Strong. 2003:202).

The team studies and evaluates relevant measuring systems to determine whether they are capable of measuring the following:

- Key input variables (for example raw material characteristics);
- Process conditions (for example temperature, speeds, pressure and flow rates); and
- Output characteristics (for example product dimensions, customer-defined specifications, product performance) with the desired precision and accuracy.

If they are not able to measure these aspects of the project, the team will work towards improving the related measurement systems before proceeding with the project (Rudisilli & Clary as quoted by Britz, 2008:21).

Once the list of metrics has been compiled, the team prioritises it to focus on its efforts on collecting the critical measures. A **prioritisation matrix** (see Annexure 2) is an efficient tool that allows the team to apply its collective understanding of the process and its outputs to the potential metrics identified.

The team proceeds to create a **data collection plan** (see Annexure 2). The existing metrics used to evaluate the process are not sufficient for developing a detailed understanding of what is

happening in the process, and therefore new metrics are needed. A sound data plan in this regard includes the following (Rath & Strong (2003:202):

- Solid operational definition of each metric;
- The type of data being collected (discrete or continuous); and
- A plan for recording the data

After asking questions aimed at establishing who is involved what machines suppliers, or equipment are being used, where the problems occur and when, the team develops a strategy for looking at the data once it has been collected to avoid having to go back and collect additional data.

The team needs to validate its measurement systems in order to ensure that these are adequate for detecting actual defects. A **Gage Repeatability and Reproducibility study (Gage R&R)** evaluates the effectiveness of a measurement system (Rath & Strong, 2003:203).

Once the metrics have been identified and the measurement process validated, the team can begin collecting data. Once this data has been collected, the team uses data displays to obtain an overall perspective of the process and its current state (Rath & Strong, 2003:203) (Annexure 2 gives a brief description of each 'tool'):

- **Run charts** and **control charts** help the team to understand the behaviour of the process over time and to determine whether or not the process is stable. These charts help to identify shifts, trends, or cycles in the process that can provide insight as to what potential causes are at work;
- **Histograms** are commonly used to summarise the data from a process and to determine whether the process is capable of meeting customer requirements; and
- **Pareto charts** can be useful in drilling down and focusing the team's effort to those that account for the majority of the defects, taking advantage of the 80/20 rule.

Using the sigma scale, the team determines the capabilities of the process to meet customer requirements. The current sigma level is used to validate the success of the project later on. The final step of the measuring phase is to update the problem statement and the team charter using the data to zero in on a specific problem.

Completing the measurement phase ensures the following (Rath & Strong, 2003:204):

- That metrics have been identified and defined and that the data has been collected (data collection plan);
- That the measurement system has been validated (Gage R&R);
- That data displays have been used to determine whether the process is stable and how much variation is present in the current process (data displays); and
- That the ability of the current process to meet the customer needs has been established (process capability).

### 2.3.3.3. Analysis phase

The team performs graphical and statistical analyses on historical and newly-obtained data with a view to develop preliminary hypotheses for improvement. The team identifies the root cause of problems and the enablers of poor performance that need to be corrected (Rudisilli & Clary as quoted by Britz, 2008:21).

Tools (refer to Annexure 2) frequently used during the measurement phase include the following:

- **Detailed process map and value-added flow analysis** – The first part of the analyse phase is aimed at identifying potential causes. Developing a detailed process map is often the first step the team takes. Using a technique called *value-added flow analysis*, the team identifies the process steps that are value-adding and non-value-adding.
- **Cause-and-defect diagram** (also known as fishbone or Ishikawa diagram) – Using the insights gained during the measure phase, the team brainstorms suspected causes of process problems by using a cause-and-effect diagram. The Five Why technique is used to formulate theories about cause-and-effect relationships between defects and process characteristics. At this stage, the potential causes are only suspected and the data generated in the measure phase and potential additional data are now used to verify and quantify the suspect relationships.

- Statistical tools (refer to Annexure 2) are used to verify and quantify potential causes (which tools are applicable depend on the type of data available as well as the availability of historical data):
  - **Regression analysis** and **scatter plots** – These are powerful tools used to quantify the relationship between two or more continuous variables. Regression analysis not only helps to determine whether two variables are correlated, but can also reveal how strong the relationships between the two variables are;
  - **Hypothesis testing** – A technique used to compare two or more groups. Both discrete and continuous data can be used to verify hypotheses generated earlier; and
  - **Design of Experiments (DOE)** – An approach that can be used if no or insufficient historical data is available. One would rarely find a cause-and-effect relationship by passively watching a process. Using DOE the team actively changes input and process variables in order to determine the effects of these on the process output. This powerful statistical technique determines the interactions between two variables. Interactions often lead to dramatic improvements, but these can only be found by actively changing factors together. This is one of the main functions and subsequent benefits of DOE.

The team is ready to move on once the root causes have been determined.

Completing the analysis phase of the DMAIC methodology ensures the following (Rath & Strong, 2003:206):

- That potential causes have been identified (cause-and effect diagram);
- That a detailed process map has been created and a value-added flow analysis has been used to identify opportunities for streamlining the process (detailed process map); and
- That potential causes have been verified and quantified with respect to their impact on the process performance, using statistical techniques (regression analysis, hypothesis testing and DOE).

#### 2.3.3.4. Improve phase

The team designs and conducts experiments with a view to determine the optimal conditions needed to operate the process. Improvements require change. The most appropriate changes are determined by means of statistically designed experiments where process inputs or system components are varied. The resulting impact on the process outputs (related to quality, cost and customer requirements) are observed and measured. If the results are favourable, the process conditions are changed to these optimal levels (Rudisilli & Clary as quoted by Britz, 2008:22).

The team starts by generating potential solutions using tools such as brainstorming, creativity tools or other methods that help generate creative solutions. Once the team has reached consensus on the solution, it proceeds with a **cost/benefit analysis**. Once the solution has been approved, the team proceeds with an evaluation of potential implementation risks using **Failure Mode and Effects Analysis (FMEA)** (refer to Annexure 2). This is a structured approach aimed at identifying, estimating, prioritising and evaluating the risks involved in the proposed solution.

The team is now ready for implementation. If possible, the team will conduct a **pilot** on a small scale before implementing the solution across the board. Once the pilot has proven that the solution works, the team moves forward and plans the actual implementation (Rath & Strong, 2003:207).

During this phase, the team composition can change to reflect the change in focus. New team members are added to ensure that those who will manage the process going forward have had a chance to give their inputs. A formal stakeholder plan is recommended to prevent a 'not-invented-here' reaction from those who did not have the chance to participate from the start.

Completing the improve phase ensures the following (Rath & Strong, 2003:207):

- An effective solution that addresses the root cause of the problem (solution);
- An analysis that documents the potential impact of the solution as well as the cost of implementing it (cost-benefit analysis);
- A pilot phase that demonstrates that the solution work (pilot);
- An evaluation of the implementation risk resulting in preventative actions if necessary (FMEA); and
- A comprehensive plan to implement the solution, including budgets, timelines and responsibilities (implementation plan).

### 2.3.3.5. Control phase

The team maintains these optimal conditions during the control phase where audits and control systems sustain the improvements. No project is deemed completed until sufficient time has passed and evidence has been gathered to verify that the desired results have been obtained and maintained (Rudisilli & Clary as quoted by Britz, 2008:22).

In order to ensure that the solution has indeed worked, process performance is evaluated by calculating the Process Sigma.

The team uses **QC charts** and **response plans** (see Annexure 2) to document the new process plans and the measures to be allocated moving forward. Thresholds for the key performance variables are also determined. An ongoing measurement system is created to provide the process owner with all the metrics required to manage the process.

The team trains the organisation in the new process and also in terms of how to standardise existing processes in order to minimise variation going forward. Once all the elements are in place, the process owner accepts responsibility for the new process.

Although the project is completed, the team needs to ensure that the lessons learned from the project are captured in an adequate format, including ideas for potential projects that came up during the team's work. The Black Belt completes all the documentation of the project and, if required, submits it for certification.

Completing the control phase of the DMAIC methodology ensures the following (Rath & Strong, 2003:208):

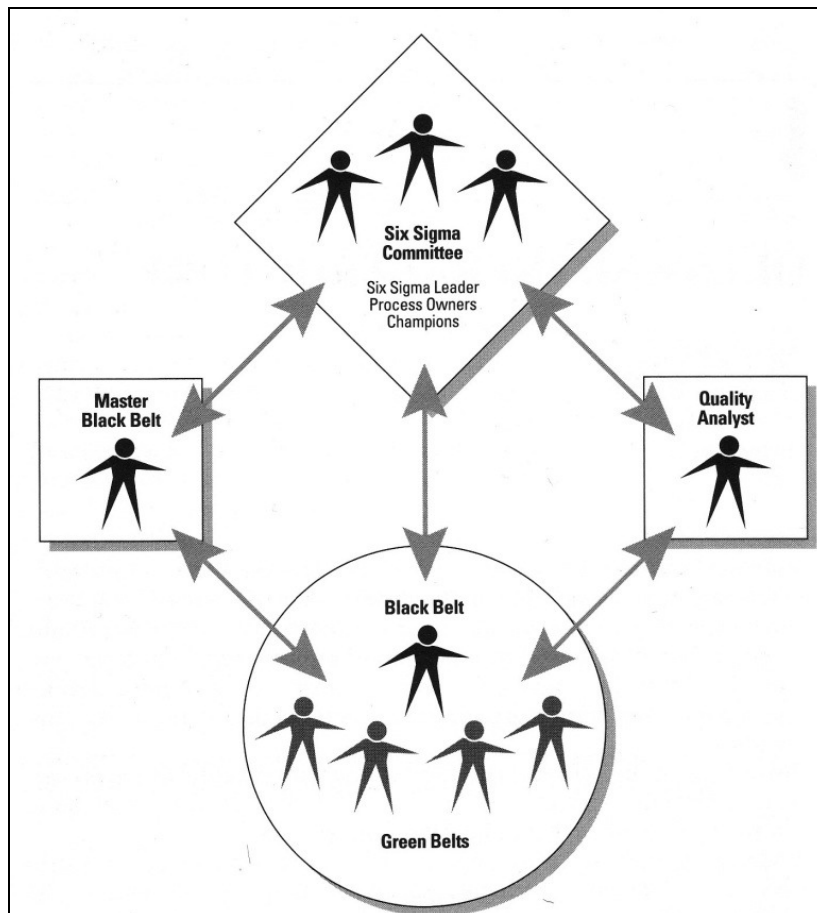
- That the results have been evaluated, documented, and approved (evaluation results);
- That the plan is in place to ensure that the gains are maintained (QC process chart or response plan);
- That a training and standardisation strategy is in place that ensures that the variation of the new process is minimal (training plan and standardisation); and
- That the project is properly documented and has been handed over to the process owner (project closer).

### 2.3.4. Six Sigma belt system

Six Sigma personnel are trained according to a hierarchy that is classed as follows:

- Six Sigma leaders;
- Process owners;
- Quality analysts ;
- Champions;
- Master black belts;
- Black belts; and
- Green belts.

Figure 2-30 shows these roles of the protagonists of a Six Sigma organisation. The following section discusses how these roles relate to each other.



**Figure 2-30: Six Sigma organisations**  
(Rath & Strong, 2003:58)

The Six Sigma **Leader** is a member of the executive leadership team and should report directly to the executive sponsoring the Six Sigma initiative. As a member of the steering committee, the Six Sigma Leader is the liaison between the steering committee and the team, coaching managers and supervisors. The Six Sigma Leader's role is to learn how to facilitate employee involvement in the process and to ensure that executives and facilitators gain the necessary skills for continued success (Rath & Strong, 2003:77). Figure 2-31 shows an example of a Leader's job description.

Job Description: Six Sigma Leader
Reporting to: CEO or local business unit leader
<b>JOB PROFILE</b>
<ul style="list-style-type: none"> <li>• Facilitate the selection of projects</li> <li>• Plan and coordinate Six Sigma training activities, as required</li> <li>• Trained at Green Belt level or beyond</li> </ul>
<b>CHARACTERISTICS, SKILLS, AND CAPABILITIES</b>
<ul style="list-style-type: none"> <li>• Senior, seasoned executive</li> <li>• Strategic thinker</li> <li>• Respected by peers</li> <li>• Excellent communicator at all levels</li> <li>• Able to influence and lead teams; able to work effectively at multiple levels within the organization</li> <li>• Energetic, enthusiastic, with a passion for excellence</li> </ul>

Figure 2-31: Example - Six Sigma Leader job description

It is crucial for a company to identify who owns a process that the Green Belt or Black Belt is working on (Rath & Strong, 2003:73). The **Process Owner** must take over the project once it is completed to ensure that gains are maintained. Failure to address this issue leads to a return to previous performances levels, eradicating the gains achieved by the Six Sigma project.

**Quality Analysts** (also known as "Money Belts") are financial representatives whose role is to ensure that the financial and nonfinancial benefits of Six Sigma projects are real (Rath & Strong, 2003:70). They are responsible for the verification of the project's business case, the validation of the business impact of the completed project and the accurate and proper reporting of the project's savings.

The **Six Sigma Champion** is the quality leader whose role is the implementation and deployment of the Six Sigma programme. His/her responsibilities also include mentoring of Master Black Belts and Black Belts. His/her role is to look at the strategic issues and see how the Six Sigma programmes and projects fit into the firm's strategic plan. He/she is central to the successful integration of Six Sigma into an organisation, because without the Champion Six Sigma becomes

an add-on tool that concentrates on individual projects which may bring short-term financial success, but it may not be priority for the strategic improvement and long term success (Britz, 2008:20).

The Master Black Belt is a full-time Six Sigma practitioner and must have completed a number of Six Sigma projects. The Master Black Belt provides mentoring support to the Black Belts as well as strategic help to the Champion (Britz, 2008:20). Figure 2-32 shows an example of a job description of a Master Black Belt.

<b>Job Description: Master Black Belt</b>	
<b>Reporting to:</b>	Six Sigma leader
<b>JOB PROFILE</b>	
	<ul style="list-style-type: none"> <li>• Support improvement activities at company, supplier, or customer locations</li> <li>• Provide mentoring and support to Black Belts, Green Belts; coach local teams to use the improvement tools appropriate to the problem</li> <li>• Master Six Sigma theory and application</li> <li>• Train/coach others within company, customers, or suppliers</li> <li>• Promote and support improvement activities in all business areas</li> <li>• Network with other Master Black Belts</li> </ul>
<b>CHARACTERISTICS, SKILLS, AND CAPABILITIES</b>	
	<ul style="list-style-type: none"> <li>• Certified Six Sigma Black Belt; completed Master Black Belt training or demonstrated completion of a similarly structured program</li> <li>• Educated to degree level or equivalent</li> <li>• Two+ years experience or thorough and proven working knowledge of Six Sigma</li> <li>• Technically strong in mathematics, statistics, and use of statistical software</li> <li>• Willingness to embrace change and new ideas</li> <li>• Tough, resilient, and able to persuade others</li> <li>• Able to work at multiple levels within the organization</li> <li>• Energetic, enthusiastic, with a passion for excellence</li> <li>• Proactive leadership style; able to communicate at all levels</li> <li>• Able to promote the key messages of pace, results, and sustainability in all activities</li> <li>• Able to quickly grasp the bigger picture of business drivers and infrastructure</li> <li>• Able to build consensus and work collaboratively as part of the worldwide Six Sigma team</li> </ul>

**Figure 2-32: Example - Master Black Belt job description**  
(Rath & Strong, 2003:66)

The **Black Belt** is a full-time specialist practitioner, trained in the use of advanced Six Sigma tools and problem-solving techniques. Such specialists lead improvement projects and are often used to train Green Belts (Britz, 2008:21). Figure 2-33 shows an example of a Black Belt job description.

Job Description: Black Belt
<b>Reporting to:</b> Master Black Belt or local Six Sigma leader
<b>JOB PROFILE</b>
<ul style="list-style-type: none"> <li>• Complete Black Belt training and achieve Black Belt certification</li> <li>• Lead three to four Six Sigma projects per year, each delivering a significant bottom-line improvement</li> <li>• Lead, train, and mentor Green Belts in the use of Six Sigma tools and techniques</li> <li>• Facilitate the selection of Green Belt projects</li> <li>• Support Six Sigma training activities, as required</li> <li>• Carry out other duties and tasks, as requested, by the Master Black Belt or Six Sigma leader</li> </ul>
<b>CHARACTERISTICS, SKILLS, AND CAPABILITIES</b>
<ul style="list-style-type: none"> <li>• Self-starter who can work on own initiative with minimum supervision</li> <li>• Effective communicator at all levels</li> <li>• Able to influence and lead teams</li> <li>• Able to work effectively at multiple levels within the organization</li> <li>• Able to use the full range of Six Sigma tools</li> <li>• Computer-literate</li> <li>• Strong analytical skills</li> <li>• Ability to lead, train, mentor, and work in a team</li> <li>• Energetic, enthusiastic, with a passion for excellence</li> <li>• Potential to develop within company</li> </ul>

**Figure 2-33: Example - Black belt job description**  
(Rath & Strong, 2003:59)

The **Green Belts** are trained in the use of Six Sigma tools, but not to the same level as a Black Belt. They spend part of their time in Six Sigma projects. Their training is concentrated on problem-solving and descriptive data analysis, with less emphasis on advanced statistical methods and strategic issues which the Black Belts and Master Black Belts would require (Britz, 2008:21).

Clearly defined roles and responsibilities are of key importance to complete projects in a timely fashion. Figure 2-34 provides a blueprint for how the work on a specific project is divided.

	BEFORE PROJECT	DURING PROJECT	AFTER PROJECT
<b>Black Belt/ Green Belt</b>	<ul style="list-style-type: none"> <li>Review purpose statement with champion</li> <li>Draft rest of charter</li> <li>Select team members</li> </ul>	<ul style="list-style-type: none"> <li>Manage schedules</li> <li>Lead meetings</li> <li>Coordinate communication</li> <li>Serve as liaison with Master Black Belt, champion, and stakeholders</li> </ul>	<ul style="list-style-type: none"> <li>See that documentation is completed and lessons captured</li> <li>Monitor implementation, if appropriate</li> </ul>
<b>Master Black Belt</b>	<ul style="list-style-type: none"> <li>Assist team leader</li> <li>Help draft charter</li> </ul>	<ul style="list-style-type: none"> <li>Provide expert guidance and coaching methods</li> <li>Help the team gather and interpret the data</li> <li>Help sponsor(s) prepare for reviews</li> </ul>	<ul style="list-style-type: none"> <li>Provide guidance as needed</li> </ul>
<b>Team Members</b>	<ul style="list-style-type: none"> <li>Notified of selection</li> <li>Adjust regular work schedule</li> </ul>	<ul style="list-style-type: none"> <li>Participate in meetings</li> <li>Carry out assignments</li> <li>Contribute subject matter expertise</li> <li>Learn necessary skills and methods</li> </ul>	<ul style="list-style-type: none"> <li>Use improved methods</li> </ul>
<b>Champion</b>	<ul style="list-style-type: none"> <li>Identify goals</li> <li>Select Black Belt/Green Belts</li> <li>Assign Master Black Belt</li> <li>Draft purpose statement</li> </ul>	<ul style="list-style-type: none"> <li>Provide direction and guidance</li> <li>Review team progress</li> <li>Run interference</li> <li>Control budget</li> </ul>	<ul style="list-style-type: none"> <li>Provide ongoing support for implementation</li> <li>Ensure monitoring</li> <li>Preserve lessons learned</li> </ul>
<b>Steering Committee (includes Six Sigma leader)</b>	<ul style="list-style-type: none"> <li>Select project</li> <li>Assign champion and Black Belt</li> <li>Identify process owner</li> </ul>	<ul style="list-style-type: none"> <li>Conduct project reviews</li> </ul>	<ul style="list-style-type: none"> <li>Sign off on project</li> </ul>
<b>Process Owner</b>	<ul style="list-style-type: none"> <li>Nominate team members</li> <li>Review business case</li> </ul>	<ul style="list-style-type: none"> <li>Participate in crucial decisions</li> <li>Supply data</li> <li>Participate in project reviews</li> </ul>	<ul style="list-style-type: none"> <li>Manage improved process</li> </ul>
<b>Quality Analyst</b>	<ul style="list-style-type: none"> <li>Create business case</li> </ul>	<ul style="list-style-type: none"> <li>Validate savings</li> </ul>	<ul style="list-style-type: none"> <li>May continue to monitor</li> </ul>

**Figure 2-34: The functions of each role during Six Sigma**  
(Rath & Strong, 2003:78)

### 2.3.5. Why use process sigma as a metric?

If the metrics per million opportunities and yield are already known, why is it advisable to have another metric? Rath and Strong (2003:494) explain why it is beneficial to use the process sigma quality scale:

1. It is a more sensitive indicator than percentages. Table 2-4 shows that as process sigma increases beyond  $4\sigma$ , a  $4.5\sigma$  quality level corresponds to 99.87% yield, while a  $5.0\sigma$  quality level corresponds to 99.977% yield. A  $0.5\sigma$  increase requires a 0.107% increase in yield. A  $5.0\sigma$  to  $6.0\sigma$  increase has a corresponding increase in yield of only 0.0227%. The sigma scale allows a process to be described that produces near-perfect quality.

2. Process sigma focuses on defect reduction. Table 2-4 shows how the dpmo falls as the sigma quality level increases. Even one defect reflects a failure in the eyes of the customer. The scale is exponential: Moving from  $3\sigma$  quality level to  $4\sigma$  quality level requires a tenfold improvement, whereas moving from  $4\sigma$  to  $5\sigma$  requires a thirtyfold improvement.

Table 2-4: Process sigma quality scale

PERCENT	DPMO	PROCESS
93%	66,807	3.0
98%	22,750	3.5
99%	6,210	4.0
99.87%	1,350	4.5
99.977%	233	5.0
99.9997%	3.4	6.0

### 2.3.6. Six Sigma Conclusion

The Six Sigma methodology is a powerful approach towards improving existing business processes. The tools that are used have been known for many years, but it is when these tools are put together in a systematic order they become more powerful. Six Sigma focuses on the customer needs and uses these customer requirements to provide direction and focus throughout any improvements project. The focus on data and metrics to support decision-making, helps to ensure that results can be sustained and that the processes remain capable of meeting customer needs, even as the team is dismantled and the Black Belt moves on to the next project.

## **2.4. Theory of Constraints Lean Six Sigma (TLS)**

Reza M. Pirasteh, Ph.D., is a Master Black Belt and certified Lean leadership trainer with 23 years of experience in implementation of continuous improvement systems. According to Pirasteh (2006) the TLS model is a continuous improvement approach across the organisation as a whole. It starts with the application of the TOC management philosophy. This ensures that overview of the organisation is obtained and the constraints are identified.

### **2.4.1. Theory of Constraints Lean Six Sigma methodology**

According to Pirasteh (2006), the **TOC** philosophy is implemented as follows:

#### **2.4.1.1. Identify the constraint**

In order to solve a problem, the problem must first be identified. Goldratt's first step in his TOC methodology is to identify the constraint in the organisation.

#### **2.4.1.2. Exploit the constraint**

According to Goldratt TOC, an organisation can only perform as fast as its constraint allows. Thus, in order to increase production (throughput), the constraint needs to be broken.

#### **2.4.1.3. Subordinate other activities to the constraint**

All other activities of the organisation should be managed and controlled according to the constraint's requirements. The constraint's requirements should take priority over other activities.

#### **2.4.1.4. Elevate the constraint**

The constraint needs to be elevated according to the following guidelines:

- Ensure that the constraint's time is not wasted;
- Take load off the constraint and give it to non-constraints;
- Use quality control of constraint's parts differently;
- Prioritising systems of parts; and
- Reallocate resources.

#### **2.4.1.5. Avoid negative inertia**

Improvements that are implemented in order to elevate the constraint need to be monitored in order to address any unforeseen consequences of the change. Such improvements should also be monitored to ensure that the organisation does not fall back to previous systems.

After identifying the problem statement at a system level, a specific problem definition is developed that addresses the organisation's constraint. According to Pirasteh (2006), this is achieved by applying **Lean** principles. The following Lean steps will help to identify waste and will also assist towards targeting ways to improve it.

#### **2.4.1.6. Specify the value**

The value of a product is only determined by the customer's requirements. An investigation into these requirements needs to be conducted.

#### **2.4.1.7. Identify the value stream**

The value that customers are willing to pay for will be identified by means of a *value stream map*. Activities within an organisation need to be streamlined in order to reduce the time that inventory spends in queues and other non-value adding activities.

#### **2.4.1.8. Make value flow without any interruptions**

An investigation into the eight forms of waste needs to be conducted in order to eliminate or minimise the waste in the organisation and to increase the value flow.

#### **2.4.1.9. Let the customer pull value form the producer**

A pull system needs to be implemented where the value chain only produces on customer demand. This ensures that the correct product is delivered to the correct customer in the correct amount and at the correct time.

Once the Lean principles have been incorporated into the organisation, the **Six Sigma** methodology needs to be followed.

#### **2.4.1.10. Pursue perfection**

In order to pursue perfection, **Six Sigma's** "Design-Measure-Analyse-Improve-Control" improvement model needs to be implemented: "This enables workers to identify and isolate the sources of process deviation and systematically remove or minimize those variations" (Pirasteh, 2006). It will also help to determine the optimal settings for the critical factors that have been identified.

#### **2.4.1.11. Implement with agility**

The final step of the TLS methodology is to institute standard operating procedures and control mechanisms in order to prevent the production system from drifting back to its initial state.

### **2.4.2. TLS case study**

Pirasteh and Farah (2006:1) conducted a study with a view to investigate the impact of implementing TLS versus standalone Six Sigma and Lean. TLS was introduced as a complement to the existing Lean and Six Sigma practices and deployed at 21 plants in a pilot program.

The assignment of methodologies was as follows:

- 11 plants applied Six Sigma;
- 4 plants applied Lean; and
- 6 plants applied TLS.

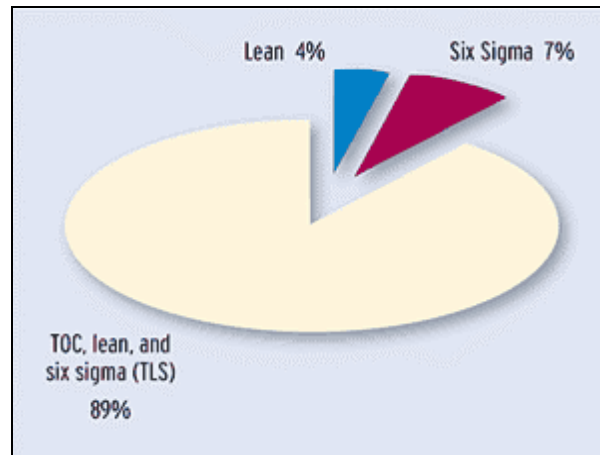
According to Pirasteh and Farah (2006:1), the 211 team leaders in these 21 plants had been trained in - and were using - one of these three methodologies. Over the more-than-two-year study, the plants completed 101 projects in all. These tasks were studied for accuracy in claimed improvements, savings, and approach.

The firm measured and tracked a series of process indicators as its key measurements, which became drivers for project selections. These measurements included:

- On-time delivery;
- Warranty costs;
- Customer returns;
- Inventory reduction;
- Cycle time reduction; and
- Scrap expense.

The following results were obtained from the study conducted by Pirasteh and Farah (2006:3) (refer to Figure 2-35):

- The TLS process improvement methodology delivered considerably higher cost savings to the company;
- A contribution of 89% of the total savings was reported;
- Six Sigma made a 7% contribution to company savings; and
- Standalone Lean applications made a 4% contribution to savings.



**Figure 2-35: Percentage of contribution to savings realised**  
(Pirasteh & Farah, 2006)

According to Pirasteh and Farah (2006:3), an operations manager at the firm reported seeing the value in TLS at all levels of the company. In post-trial interviews, he noted that employees have been energised and were feeling a renewed sense of pride in their accomplishments. He was also enjoying the positive results firsthand, noting, “I have been the beneficiary of more than a tenfold return on this investment.”

Furthermore, the vice-president and general manager were no longer frustrated. According to Pirasteh and Farah (2006:1), they referred to the TLS programme as a complete success and could see the results of their employees’ hard work. “After being introduced to the TLS approach,” they said, “we all knew within a very short period of time that this was what had been missing in our efforts.”

## ***2.5. Literature survey: Summary and conclusion***

In this chapter, an overview of all three foundational methodologies (Theory of Constraints, Lean and Six Sigma) has been presented, as well as the TLS methodology in which the three methodologies are combined into a process that supposedly has an even greater effect on an organisation.

Concluding this chapter, the TLS methodology can be summarised as follows:

1. TOC is used to identify the constraint within an organisation. When implementing a continuous improvement project, it is difficult to determine where to start. The constraint is

used as a starting point from where one proceeds to improve the throughput of the entire organisation;

2. Lean principles are implemented in order to guide the improvement of the constraint and the rest of the organisation by identifying the waste in the organisation and reducing or eliminating it; and
3. Once the organisation has eliminated all possible forms of waste and the processes have stabilised, Six Sigma can be implemented. The Six Sigma methodology is followed with a view to pursue perfection and to prevent the organisation from falling back into old processes and procedures. Six Sigma also assists in determining the root causes of deviation and consequently inhibiting these causes.

In order for the TLS methodology to address Jonker Sailplanes' specific needs, the methodology needs to be adapted. The following reasons are stated for this adaptation of the TLS methodology:

1. Jonker Sailplanes is a relatively new organisation and therefore has not yet clearly defined their philosophy, objectives and goals;
2. Contrary to Toyota, Jonker Sailplanes is not a mass-manufacturer that has large batches of inventory that pass through the production processes. The parts made by Jonker Sailplanes are hand-manufactured. Therefore, Lean principles need to be adapted for Jonker Sailplanes' requirements;
3. Jonker Sailplanes has only recently passed through the transition from prototyping to production. Therefore, the production environment is not as highly developed as in many other manufacturing organisations;
4. The leadership within Jonker Sailplanes has not yet developed to its full potential; and
5. Jonker Sailplanes has not yet established a trusting relationship with their suppliers.

The Jonker Sailplanes-customised TLS methodology is presented in Chapter 3.

## **Chapter 3 : Theory of Constraints Lean Six Sigma implementation plan for Jonker Sailplanes**

In this chapter, the adapted TLS implementation plan for Jonker Sailplanes is discussed with reference to the literature survey and the conclusions set out in Chapter 2. Section 3.1 presents the TLS implementation plan for Jonker Sailplanes. Although the implementation plan makes reference to TOC, Lean and to Six Sigma, Six Sigma was not implemented at this point in time. In Section 3.1, an explanation and motivation are offered for rather recommending this implementation of Six Sigma for future research.

### ***3.1. Implementation plan for Jonker Sailplanes***

The adapted TLS implementation plan for Jonker Sailplanes is divided in to the following 14 steps:

1. Specify the organisation's long-term philosophy;
2. Identify the constraint;
3. Exploit the constraint;
4. Subordinate other activities to the constraint;
5. Elevate the constraint;
6. Avoid negative inertia;
7. Specify the value;
8. Identify the value stream;
9. Make value flow without any interruptions;
10. Let the customer pull value from the producer;
11. Focus on the people in the organisation and the partners outside the organisation;
12. Implement with agility;
13. Become a learning organisation; and
14. Pursue perfection.

These 14 steps are discussed below:

#### **3.1.1. Step 1: Specify the organisation's long-term philosophy**

The organisation needs to brainstorm and agree upon their long-term philosophy. All decisions that are made within the organisation need to be in line with this philosophy.

### **3.1.2. Step 2: Identify the constraint**

The constraint determines the drumbeat of the organisation. Therefore, in order to increase the throughput, the constraint needs to be identified (and elevated).

### **3.1.3. Step 3: Exploit the constraint**

The constraint should be utilised in order to determine the root cause of the delays. These root causes should be addressed in order to prevent the delays from reoccurring.

### **3.1.4. Step 4: Subordinate other activities to the constraint**

All activities within the organisation must be prioritised according to the needs of the constraint.

### **3.1.5. Step 5: Elevate the constraint**

Elevate the constraint by means of the following TOC principles:

- Ensure that the constraint's time is not wasted;
- Take load off the constraint and give it to non-constraints;
- Increase quality control of parts that are supplied to the constraint;
- Implement a priority system for all parts that are supplied to the constraint;
- Allocate additional resources to the constraint.

### **3.1.6. Step 6: Avoid negative inertia**

The Plan-Do-Check-Act method should be followed when making any changes in the above-mentioned steps of the TLS implementation plan.

### **3.1.7. Step 7: Specify the value**

The value of a product is determined by the customer. If the product is not manufactured according to his liking, the value of the product, according to the customer, will decrease. This will influence the customer's decision in terms of whether or not to purchase the product. Therefore,

one should ensure that the product is manufactured according to the value that is specified by the customer's requirements.

### **3.1.8. Step 8: Identify the value stream**

In order to manufacture an aircraft according to the customer's requirements, a certain value stream needs to be followed. The purpose of a value stream map is to determine the areas where waste is present.

When drawing a value stream map for large batching plants, the waste is usually identified as the waiting between the working cells. Large amounts of inventory are usually waiting to be processed. Reducing the batch sizes and changing the sequence of tasks usually solve the problem.

At Jonker Sailplanes, the waiting in between production cells is not the problem. Rather, large amounts of waste are found within each production cell. Therefore, a partial value stream map should be drawn of the work performed *within* a single production cell ('partial' refers to only the part of the value stream map that shows the timeline indicating the value-adding and non-value adding activities). Findings from this sample cell's value stream map should then be generalised in order to be made applicable to all the production cells.

### **3.1.9. Step 9: Make value flow without any interruptions**

The value stream map was used to determine which areas needed improvement. In order to ensure that the value flowed throughout the production of an aircraft, the seven Lean principles in the Process Category need to be implemented within each production cell at this stage of the implementation plan:

1. Principle 2 - Create continuous process flow to bring problems to the surface;
2. Principle 3 – Use a “pull” systems to avoid overproduction;
3. Principle 4 - Level out the workload (work like the tortoise, not the hare);
4. Principle 5 - Build a culture of stopping to fix problems, to get quality right the first time;
5. Principle 6- Standardised tasks are the foundation for continuous improvement and employee empowerment;
6. Principle 7 - Use visual control so that no problems are hidden; and

7. Principle 8 – Use only reliable, thoroughly tested technology that serves one’s people and processes.

### **3.1.10. Step 10: Let the customer pull value from the producer**

Aircraft should be manufactured according to the specific customer requirements. Therefore, value-adding activities should be determined by the customer.

### **3.1.11. Step 11: Focus on the people in the organisation and the partners outside the organisation**

People are the most valuable asset of any organisation, whether these people are employees within the organisation or suppliers of the organisation. Therefore, people should be dealt with accordingly – this approach is explained by the following Lean principles:

1. Principle 9: Grow leaders who thoroughly understand the work, live the philosophy and teach it to others;
2. Principle 10: Develop exceptional people and teams who follow the company’s philosophy; and
3. Principle 11: Respect the extended network of partners and suppliers by challenging them and helping them to improve.

### **3.1.12. Step 12: Implement with agility**

Once the implementation of the continuous improvement project has been completed, the different production cells have to be managed and monitored closely initially. This is necessary in order to keep the employees motivated, to identify any problems and to prevent employees from falling back to old processes and procedures.

### **3.1.13. Step 13: Become a learning organisation**

Once the continuous improvement project has been implemented, the organisational culture should change to one that strives to become a learning organisation by means of the last three Lean principles:

1. Principle 12: Go and see for yourself to thoroughly understand the situation;
2. Principle 13: Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly; and
3. Principle 14: Become a learning organisation through relentless reflection and continuous improvement.

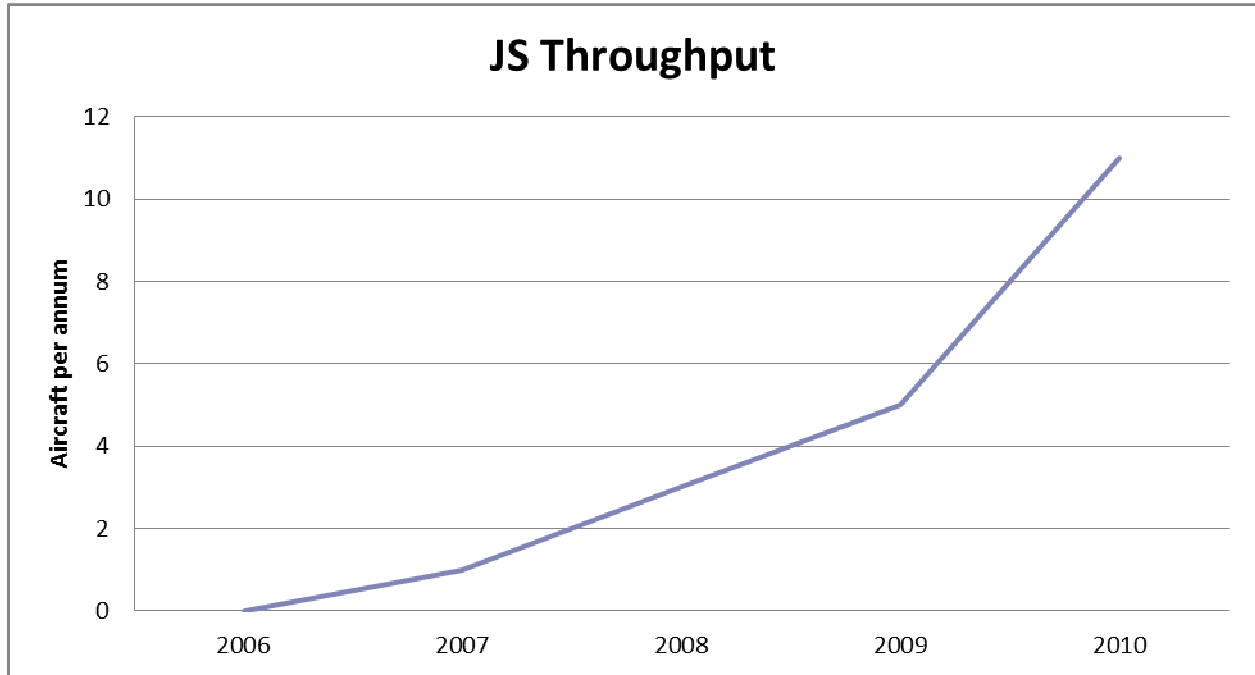
### **3.1.14. Step 14: Pursue perfection**

Once the production flow has been streamlined, the organisation should proceed from implementing Lean projects towards implementing Six Sigma projects.

Six Sigma focuses on eliminating variation and ensures that manufacturing takes place according to customer requirements. The DMAIC Six Sigma tools should be used to pursue perfection in the products that are manufactured.

### 3.1. Implementation of Six Sigma at Jonker Sailplanes

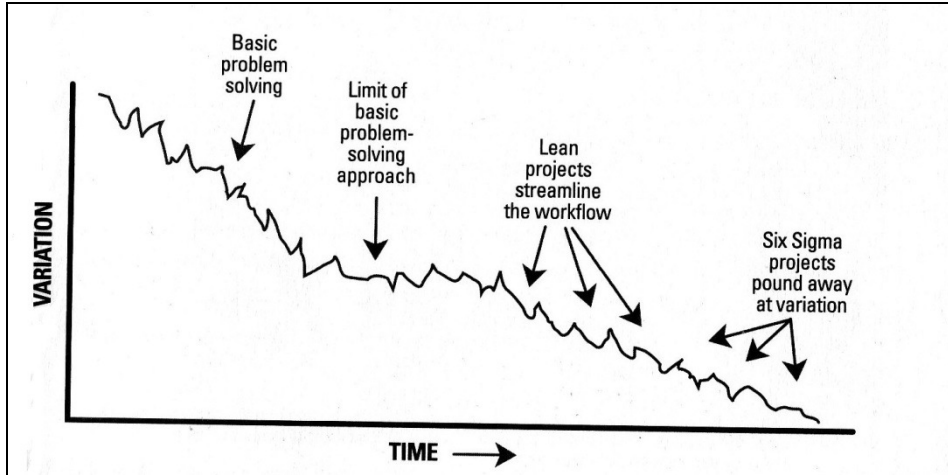
TOC and Lean were implemented in Jonker Sailplanes during 2009 throughout 2011. This gave rise to a very steep incline in the number of aircraft manufactured per annum (see Graph 3-1)



Graph 3-1: Jonker Sailplanes throughput

During 2011 the throughput only began to stabilise at 15 aircraft per annum.

**Note:** The purpose of applying TOC was to identify the constraints within Jonker Sailplanes. The purpose of implementing Lean was to optimise these constrains (and the rest of the organisation). In contrast to these continuous improvement methodologies, the purpose of Six Sigma is to maintain the improvements and prevent the human tendency to slow down after a pinnacle in throughput was reached. Six Sigma is also primarily concerned with eliminating variation (Rath & Strong, 2003:127). Figure 3-1 indicates how an organisation proceeds through the transition from Lean to Six Sigma.



**Figure 3-1: Transition from Lean to Six Sigma**  
(Rath & Strong, 2003:127)

Jonker Sailplanes is still in the phase where Lean projects are streamlining the workflow. Therefore, Six Sigma can only be implemented once the throughput has reached a stable rate of at least 18 aircraft per annum. It is forecasted that throughput will stabilise at 18 aircraft per annum from 2013 onwards. Only when the workflow is streamlined, will it be possible to move from implementing Lean project to implementing Six Sigma projects at Jonker Sailplanes.

### **3.2. Conclusion**

The TLS implementation plan was adapted to address the specific needs of Jonker Sailplanes. This adapted 14-step implementation plan was presented in Chapter 3. The implementation plan was followed at Jonker Sailplanes and the effects that the implementation had on the organisation are discussed in Chapter 4.

## **Chapter 4 : Implementing Theory of Constraints Lean Six Sigma (TLS) at Jonker Sailplanes**

Throughout this chapter detail is provided regarding how the adapted TLS methodology was implemented at Jonker Sailplanes and the impact that it had on the organisation. This chapter also gives reference to recommendations that are suggested for further improvements.

### ***4.1. Specify the organisational long term philosophy***

It was found that Jonker Sailplanes had not formulated a long-term philosophy. It was evident that this shortcoming in the business structure caused difficulties when making decisions in the organisation. It was difficult to decide to which product development projects the organisation should contribute resources, were to invest developing funds, in which direction the training of the employees should go, and so forth. All options sounded acceptable at the time, but these could not be prioritised according to objective of the organisation.

Refer to Section 8.1 for the recommendation.

### ***4.2. Identify the constraint***

A constraint is normally identified by a heap of excess inventory in front of it, waiting to be processed. In Jonker Sailplanes's case it was not that simple to identify the constraint, because there were no heaps of inventory waiting for the following cell to process it. Most of the production cells were actually waiting for the inventory. This was the first indication that the constraint was close to the start of the production line.

During 2010, Jonker Sailplanes was supposed to deliver one aircraft at the end of each month. During the second half of the year no aircraft were delivered and during December 2010 five aircraft had to be delivered because of the backlog that had accumulated. The illusion was formed that Final Assembly was the constraint, because they were not delivering aircraft. However, after closer examination it was found that this was not true, because there were never any aircraft waiting in front of Final Assembly to be completed. Final Assembly was actually waiting for aircraft to reach them. This was a case of *accumulative slowness*. This TOC

phenomenon occurred because of each production cell in the production line slowly started to fall behind. This lost time was never recovered. Instead, it accumulated until it reaches the last cell.

After performing a root cause analysis, it was found that each preceding production cell was the constraint for the following cell. This was the second indication that the constraint was close to the start of the production line.

The root cause analysis pointed out that the two Pre-close Assemblies (wings and fuselage) were the constraints and more specifically the Wing Pre-close Assembly.

This is one of the production cells where many parts and sub-assemblies are fitted together for the first time to be assembled into a new assembly. Therefore, numerous problems surface during this production cell. The cell itself was not so much a constraint, but rather the combination of the suppliers to the pre-close assembly.

### ***4.3. Exploit the constraint***

The advantages of identifying a constraint in an organisation is that it makes it possible for one to focus the energy required to incorporate improvements in the area where it would have the most significant impact on the entire organisation. The constraint needs to be the starting point for any continuous improvement project.

The constraint was also used to determine where to implement further continuous improvement projects (outside of the constraint). If, for example, it was found that a part needed to be reshaped before bonding it into the Wing Pre-close Assembly, the mould of the part would be changed in order to provide a better fit of the part without having to modify it.

Within the organisation there are hundreds of suggestions towards improvement that could be implemented and all of these can be said to be good suggestions. Unfortunately, implementation of such ideas requires time, money and resources, and the organisation does not have an abundance of these.

The constraint was therefore used to determine which continuous improvement suggestions to implement first. Although all the improvement suggestions had some validity, improvements that would take the load off the constraint would take priority over other suggestions.

Furthermore, according to the TOC literature, the constraint determines the drumbeat of an organisation. If the constraint's capacity is not increased, the organisation's performance will not increase. Therefore, implementing any suggestions other than those that will actually improve the constraint, will only lead to local optimisations instead of organisational optimisation.

Using the constraint to prioritise the improvement suggestions ensured that time, money and resources were used where it would have the most significant impact on the entire organisation.

#### ***4.4. Subordinate other activities to the constraint***

Activities preceding Wing Pre-close Assembly were evaluated and were subordinated as follows:

- Composite parts that were supplied to the constraint were built first to ensure that the parts were available when required by Wing Pre-close Assembly. Should a part be scrapped, there would be enough time to build a replacement part;
- The Kitting Coordinator gave priority to the Wing Pre-close Assembly kit to ensure that all parts were available when required by Wing Pre-close Assembly; and
- The manufacturing process of the wing skins were improved to ensure a better fit of all the parts that had to be assembled into the skins.

Subordinating other activities to the constraint ensured that the constraint was protected. Referring to the TOC literature study, the cost of an hour lost at a constraint is equal the operating expenses of the organisation for an hour. Therefore, the organisation cannot afford to lose an hour on a constraint. The constraint can never idle, because of parts that are delivered behind schedule.

### **4.5. Elevate the constraint**

Referring to Goldratt's principles, the constraint was elevated as follows:

1. Ensure that the constraint's time is not wasted
  - Idle time was reduced by ensuring the Wing Pre-close Assembly kit would be available when it is required;
2. Take load off constraint and give it to non-constraints
  - All tasks that are performed by the constraint were evaluated to determine which tasks could be allocated to other resources. Where possible, tasks were re-allocated to preceding production cells;
3. Use quality control of constraint's parts differently
  - The inspection of Wing Pre-close Assembly parts are done rigorously to ensure that Wing Pre-close Assembly does not perform work on defective parts that will be scrapped afterwards;
  - A thorough inspection of the wing skins are performed after demoulding before any further work is performed on the wings;
4. Priority-system
  - Parts that are manufactured by preceding production cells and supplied to the constraint take priority over other parts; and
5. Reallocate resources
  - People were moved from a non-constraint to the constraint in order to increase the constraint's capacity.

Initially, production cells were reluctant to change their priorities and processes in order to assist another production cell. People were also reluctant to move to other production cell. They preferred to rather change processes that would improve their own production cells.

#### **4.6. *Avoid negative inertia***

It was difficult not to lose momentum in the project. A few weeks after implementation, the focus started to drift to problems that seemed bigger and more urgent than those of the constraint. The constraint started to lose support from the factory.

Suggestions were made regarding how to improve the capacity of the constraint. However, changes were implemented that were not thoroughly thought through and planned. These changes caused problems within the Wing Pre-close Assembly and they were not able to complete their allocated tasks on time.

The Plan-Do-Check-Act approach was followed for all changes that were made. The constraint was closely monitored in order to evaluate the impact of all changes, whether it was good or bad.

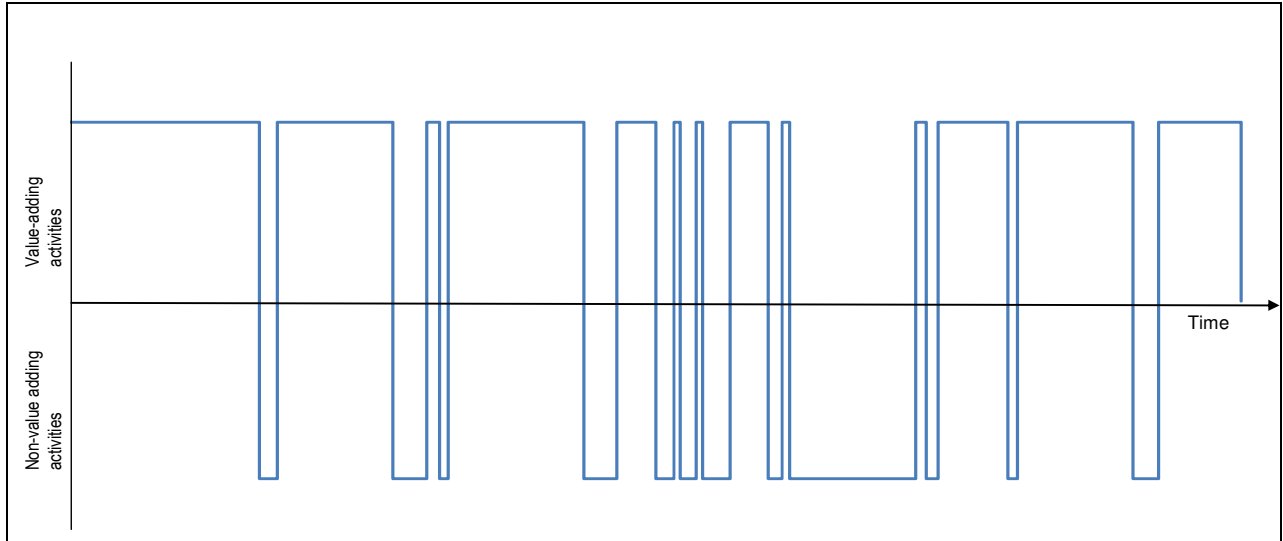
Consequently, the changes saved time on the next production cycles and the constraint was able to recover after falling behind schedule.

#### **4.7. *Specify the value***

At Jonker Sailplanes, the value of an aircraft is determined by the customer. A customer-coordination file is compiled by the marketing agent. All the different options that are available on an aircraft are noted in the file and the customer's requirements are recorded. Manufacturing of the aircraft is done strictly according to these requirements.

#### **4.8. *Identify the value stream***

The partial value stream map of the Final Assembly production stage was drawn (see Figure 4-1). All activities above the line are value-adding activities and those below the line are non-value adding activities. The length of the horizontal lines shows the duration of each activity. The data used to draw the value stream map is available in Annexure 1.



**Figure 4-1: Partial value stream map for Final Assembly**

Although a very short timeline (approximately one month) is shown in the partial value stream map, the frequent changes between value-adding activities and non-value adding activities are apparent. These frequent changes were of greater concern than the duration of the non-value adding activities.

A root cause analysis was conducted in order to determine the reasons for the frequent change between value-adding and non-value adding activities within the Final Assembly production stage. Suggestions towards improving the situation were implemented in order to inhibit these causes of change (see Table 4-1).

**Table 4-1: Root causes for frequent changing between value-adding activities and non-value adding activities**

Root cause within sample cell	Improvement suggestion for all other production cells
The Team Leader did not check his kits before starting to work	All Team Leaders should check all their kits prior to starting their cycle.
When working overtime, the Team Leader did not arrange for keys for his stores. He was therefore, unable to obtain parts and materials from the store to complete his work	All Team Leaders should plan before working overtime and make all necessary arrangements. They should also ensure that they have collected all tools, parts and materials before starting a task.
The Team Leader works in an unfocused manner. He starts a task and then leaves it to start another task.	All Team Leaders should do daily planning and have the discipline to stick to this

<p>After a few minutes he stops this task, and starts another task. This happens even when no external factors are preventing him from completing a task.</p>	<p>planning throughout the day.</p>
<p>The final assembly area is too big. There is too much space for clutter and the Team Leader has to walk around too much.</p>	<p>Different areas within each applicable production cell should be assigned for the fuselage and the wings. Workbenches should be built according to such requirements. Air pipes, extension cords and the like should also be laid out according to this.</p>
<p>The end of the compressed air pipe is always thrown on the ground and then needs to be picked up again.</p>	<p>A main line and a manifold with four quick couplers should be placed under the each workbench.</p>
<p>The Team Leader does not plan the tasks for the day. This causes him to stop and think each time before he can start the next task. When problems arise and he is prevented from performing a task, he is uncertain as to what the next task is.</p>	<p>All Team Leaders should do daily planning and have the discipline to stick to this planning through the day.</p>
<p>The Team Leader tends to postpone tasks that he is less fond of. This prevents tasks from happening in the best order.</p>	<p>A generic plan should be compiled for each cell and the Team Leader must have the discipline to stick to it</p>
<p>The Team Leader does not have a horizontal surface to work on close to the fuselage. Each time this is required for a task to be done, he works in a different place in his area. This causes a lot of motion. Because each task is done in a different place, his tools are misplaced over the area, causing him to look for his tools most of the time.</p>	<p>Where necessary, Team Leaders should be supplied with portable tables (trolleys), which they can move around the fuselage/wings as they work. Their tool board could also be attached to these.</p>
<p>Before starting a task, the Team Leader does not stop and think of all the tools / parts that he is going to need to complete the task. This means that he works for a few minutes and then has to fetch a tool / part. After continuing with the task for a few minutes he has to get up again to fetch another tool / part.</p>	<p>The manufacturing procedure should specify the required tools for each task.</p>
<p>The Team Leader tends to not complete a task fully.</p>	<p>Team Leaders need to work in a more systematic manner and complete a task up to standard before starting with the next task.</p>

## **4.9. Make value flow without any interruptions**

The value stream map was used to determine the areas that needed improvement. In order to ensure that the value flowed throughout the production of an aircraft, the seven Lean principles in the Process Category were implemented throughout the organisation. The seven Lean principles are the following:

1. Create continuous process flow to bring problems to the surface;
2. Use “pull” systems to avoid overproduction;
3. Level out the workload (Work like the tortoise, not the hare);
4. Build a culture of stopping to fix problems, to get quality right the first time;
5. Standardised tasks are the foundation for continuous improvement and employee empowerment;
6. Use visual control so that no problems are hidden; and
7. Use only reliable, thoroughly tested technology that serves your people and processes.

The impact of implementing these seven Lean principles is discussed bellow:

### **4.9.1. Create continuous process flow to bring problems to the surface**

Jonker Sailplanes needed to undergo a transformation: from a prototyping set-up to a proper production line. There was no structured system in place and responsibilities were not clearly defined. All skills and energy were applied to the assembly of a single aircraft, and this prevented parts and sub-assemblies to be ready once the aircraft left the factory.

A schedule had been implemented which divided the work into equally distributed 20-day production stages in order to form a production line. Consequently, responsibilities were allocated accordingly and employees only focussed on their own 20 days of work.

By forcing the workers to keep to a schedule, many of problems surfaced, which had to be solved in order to improve the production tempo.

### **4.9.2. Use “pull” systems to avoid overproduction**

Jonker Sailplanes used to produce aircraft without a proper functioning schedule. There was no flow in the factory. Most workers focussed on one aircraft at a time.

Implementing the schedule at Jonker Sailplanes is not seen as a push system. JS is unique in the sense that it assembles a small amount of large components, unlike Toyota. This is not considered to be mass production.

Also, manufacturing aircraft requires long lead times. Therefore a schedule is required in order to commit to realistic delivery dates for customers according to their specific needs (for example being available for competitions).

The schedule ensures that there is flow in the production line without over production. During the assembly phase it is impossible to overproduce parts, because the Team Leader only has the one aircraft to work on. Cells that manufacture the small composite parts and metal parts manufacture parts according to the kitting system, thus preventing them from overproducing. Parts are not mass-produced by machines as handmade parts are used. This method also restricts overproduction.

However, everyone used to go to the different stores to collect the parts that they required. To address this, a kitting system was implemented in order to pre-pack all the required parts and sub-assemblies for a particular production stage before the Team Leader requires these. This ensures that the Team Leaders do not have to search or wait for parts. These kits consist of composite parts, metal parts and OTS (off-the-shelve) parts that are procured from outside JS by the Logistics Manager. Therefore, the Composite and Metal Team Leaders together with the Logistics Manager are considered to be kitting suppliers. The composite and metal parts are not kept in stores (excess inventory); the parts go straight from production into the kit.

Since the kits are put together three weeks in advance, the kitting process also functions as an early warning system to ensure that there are no shortages when the Team Leaders start with their cycle. If any shortages are identified by the Kitting Coordinator, the Kitting Suppliers have three weeks to supply the parts, therefore not delaying the Team Leaders.

Additionally, the kitting system functions as a *kanban* system. Once a kit is taken from the kitting area, this signals the need for the next kit to be packed. Thus, the kiting system ensures that the Team Leaders receive their parts JIT. The kit is brought to the Team Leaders by the Kitting Coordinator and therefore the Team Leader does not have to walk around (motion = waste) looking for parts to be build into the aircraft.

Furthermore, functions the kitting system as a buffer system. When parts are scrapped further down the production line or shortages occur for any other reason, the kitting systems highlights the problem and the kit suppliers have three weeks to supply the parts, thus preventing shortages in the production line.

#### **4.9.3. Level out the workload - Work like the tortoise, not the hare**

**Muri** - Due to rework and other causes of delays, overtime is required within certain production cells. 15-hour days are often required for extended periods of time.

The constraint used to cause delays in the delivery of aircraft, which then required overtime. This problem was addressed by protecting the constraint and ensuring that it always had the correct parts at the correct time. In turn the kitting system functions as a buffer, with the intent of solving part shortages before a production cell requires the parts. This will ensure that the Team Leader can start with his 15 days of work when the schedule requires it and no extra energy will be required at the end of the 15 days to ensure that the work is completed on time. By preventing the constraints from falling behind the schedule, delays do not accumulate to further production stages, thus preventing the need for overtime.

**Mura** – Because of various reasons, it often happens that a resource is prevented from doing his allocated work. Once he is able to continue, he has to make up for lost time to prevent the production schedule from slipping and to prevent the proceeding cell from also having to wait. This also causes Muri.

One of the production management tools that were put in place is the use of the *Production Delay Form*. Any problems that cause a delay in any cell are brought to the Production Manager's attention by means of the Production Delay Form. The form ensures that a root cause analysis is done and preventative actions are implemented. The preventative actions ensure that the delay does not happen again and the cell can continue their work according to the planned schedule, without the need for "work-arounds".

**Muda** – *Muda* within Jonker Sailplanes consists out of the following eight forms of waste:

## **1. Transportation**

Parts and assemblies used to move from one area of the factory to another and then back again in order for different tasks to be performed and also because of different tools and jigs being in different areas. The assembly of the aircraft did not flow in one direction

An assembly line was put in place where the material, parts and assemblies flow in one direction. Small composite parts are built in one end of the factory. These parts are then assembled throughout the factory until the final product leaves the other end of the factory.

Expanding the facilities and moving the tasks into a line that flows reduced unnecessary transportation of parts and assemblies.

Raw materials are received into the incoming goods area where the necessary incoming inspections, batching and labelling are performed by the Logistics Manager. The material is then distributed to the different production cells by the store man.

All raw materials have to pass through the incoming inspection process and receive batch numbers, Therefore it cannot be delivered straight to the production cells. A *kanban* system is used to replenish materials within the different cells.

Due to the relatively small facility at Jonker Sailplanes, this is not yet a concern.

## **2. Excess Inventory**

Jonker Sailplanes used to have a store for composite parts. This however created unnecessary excess inventory.

The composite store is no longer in use and was replaced by the kitting system. Parts are only produced as fast as the kitting system requires it, because there is no place to store extra parts.

Replacing the composite store with the kitting store made a lot of floor space available for other things than parts. It is also a visual management system that is used to identify shortages before the parts are required. By not having heaps of inventory available, problems are brought to the surface so that these can be solved.

### 3. Motion

The following used to cause waste in the form of motion within Jonker Sailplanes:

- Looking for inspectors to sign of work before continuing.

Inspectors are informed of required inspection during the daily production meeting.

The new system keeps the inspectors informed of which inspections are required, but it becomes a problem when the inspector is required to be at more than one production cell at the same time.

- Searching for stolen / borrowed tools.

Due to the cost of expensive tools, a limited amount of expensive tools are purchased and these are then borrowed between different production stages.

The following countermeasures were implemented to prevent unnecessary motion:

- Shadow boards were implemented to keep all tools neat and organised in each production cell. This serves as a visual management tool to check for missing tools
- All borrowed tools must be returned.
- A tool tag system was implemented. Each employee has a set of tags with his initial on it. Whenever a tool is taken from any shadow board (his own or someone else's) the tool must be swapped with one of his own tool tags.
- Tools that are used frequently must be ordered instead of borrowed.
- Expensive tools are kept in the tool store and signed in and out by the person who uses these occasionally.

When looking for a borrowed tool, a worker can go straight to the person who borrowed it, because the tool tag indicates who borrowed it. This eliminates the need to walk from person to person looking for the tool. The tool tag system also ensures that tools are not forgotten in an assembly of an aircraft, for example, within the wing, which is not accessible after joining the two halves. It thus prevents safety hazards from occurring.

- Walking to stores to collect raw materials, consumables and parts.

A *kanban* system was implemented for raw materials and consumables. At each cell there is a list of all the raw material and consumables that should be replenished each day. The Store Man takes the required raw material and consumables to all the different production cells, instead of all the workers walking to the store. He checks the list to ensure there is

container from which the cell is using material and that there is a full container of the same material available behind it. Thus, the *kanban* system prevents motion in the factory. This can be related to existing practices: “Ohno’s *kanban* system has proven to be enormously successful and have had far-reaching economic implications. Its installation led to the emergence of Japan as the major economic power. We are clearly seeing the results of Ohno’s approach – a substantial increase in the standard of living in Japan and the loss of our dominant position in many industries” (Glodratt & Fox, 1986:88).

#### **4. Waiting**

Building aircraft requires a tremendous amount of paperwork. Filling in paperwork takes up valuable production time and therefore needs to be done as lean as possible. Each Team Leader used to fetch different applicable forms and inspection documents from the QA office. This caused motion and waiting.

This has been addressed in the following manner: instead of fetching paperwork form the QA office one by one, Quality Packs are given to each Team Leader before they start their 15-day cycle. The Quality Pack contains all the relevant paperwork that they need to complete. They only sign once that they have received the entire Quality Pack, instead of signing for each individual form or inspection sheet when they received it. The Quality Packs prevent motion (waste) of the Team Leaders to the QA office. It also ensures that paperwork does not get lost and that the Team Leaders have the relevant paperwork JIT.

Within Jonker Sailplanes it often happens that a cell has to wait for the preceding cell to finish or the cell has to wait for parts to be completed. The problem with waiting is that there seems to be no urgency from the Team Leader to obtain the parts or assemblies that they are waiting for. They seemed to think that if they can give a reason why they are waiting it is acceptable; instead of solving the root cause.

By using the Production Delay Form, the reasons why a production cell are waiting is recorded. A root cause analysis was done to prevent this from happening again. Furthermore, the form functions as a method to bring problems to the surface: “This is important because one cannot manage that which one cannot see” (Baker, 2011).

### **5. Over-production**

This is rarely a problem at Jonker Sailplanes, since it a relatively small number of large parts are assembled. Therefore, this form of waste was not addressed within Jonker Sailplanes

### **6. Over-processing or incorrect processing**

All composite parts used to be inspected after they have been built. This was a non-value added activity since the actual composite lay-up schedule that was followed is not visible once the part is completed. The inspection of composite parts was changed to in-process inspection. This means that the actual process that was followed to manufacture the parts can be checked as well as the lay-up schedule: "Quality is not inspected into a part; it is build into a part" (Baker, 2011).

### **7. Not right first time – scrap, rework & defects**

Customer complaints are received after having delivering the products. The product is often sent back to Jonker Sailplanes for rework. This causes interruptions and delays in the production of the proceeding aircrafts, because time is spent on repairs and rework instead of manufacturing the proceeding aircraft.

In order to address this state of affairs, a non-conformance database system was implemented. All internal non-conformances as well as customer complaints are recorded in the database. A root cause analysis was conducted for each non-conformance and preventative actions are now implemented. The preventative actions prevent the non-conformances from reoccurring and by addressing the root causes other possible non-conformances are prevented.

### **8. Unused employee creativity**

Employees' knowledge and previous experience need to be used more creatively. Refer to Section 8.4 for recommendations in this regard.

#### **4.9.4. Build a culture of stopping to fix problems, in order to get quality right the first time.**

The mindset of the workers within the organisation used to be one of “production has to go on, we will fix the problems later” (which seldom then happens); this caused a significant number of problems to build up over months. The workers knew they had to fix the problems; they just “did not have the time to do it”.

In this regard one should remember that: “Preventing problems from being passed down the line is much more effective and less costly than inspecting and repairing quality problems after the fact” (Liker, 2004;130).

At Jonker Sailplanes a Quality Gate system was implemented. This is a quality/cosmetic inspection that is performed before an aircraft proceeds from one production stage to the next. Only when all the criteria have been signed off, the aircraft is allowed to proceed to the next production stage. This prevents problems from moving down the production line and accumulating in the Final Assembly stage. It also prevents teams from having to fix other teams’ tasks before they can start with their own tasks.

#### **4.9.5. Standardised tasks are the foundation for continuous improvement and employee empowerment**

At Jonker Sailplanes there used to be a lack of manufacturing procedures available according to which the product was built. There were no records available of how each individual aircraft was built and this meant there were no procedures or building records available by means of which the process could be revised when something went wrong.

In order to address this, manufacturing procedures were written for all the work that is performed on an aircraft. Additionally, in order to ensure that each Team Leader always performs his work in the most productive sequence, they now work according to their individual, pre-determined generic schedules. The generic schedules divide the allocated work for each Team Leader into working day segments. By following the generic schedule, the Team Leader can manage each day’s work. He is also able to determine on a daily basis whether he is on or behind schedule.

Contrary to the generic schedules, the master production schedule is only used to determine the deadlines for each production stage on which their work should be completed and that the aircraft will move to the proceeding production stage.

Standardised manufacturing procedures ensure high production efficiency and prevent the recurrence of defective products, operational mistakes, and accidents. This approach also incorporates workers' ideas. Due to the generic schedules for each production cell, it was possible to do better high-level planning for the entire factory.

Customers used to have a large input regarding the different options according to which their aircraft were built. This practise gave rise to a great deal of rework, because options that had already been built into the aircraft often had to be changed. It also caused delays in the manufacturing of the aircraft, because the factory often had to wait for the customer to make a decision.

Addressing this problem entailed that the aircraft had to be standardised to a 'vanilla flavour' (standard) aircraft (Baker, 2011). All the different options that the customer can choose from were put on one list. The customer has to make a decision regarding the options before an allocated date, or the option will change to the default option.

When the customer keeps to the deadlines for making decisions, the system works well. However, when a customer misses the deadline and the factory continues with the default option, rework is often required to please the customer.

#### **4.9.6. Use visual control so that no problems are hidden**

Different toolboxes and cupboards were previously used for storing tools. It was close to impossible to say whether tools were missing or possibly forgotten within components of an aircraft (something that could cause major safety problems).

In order to address this situation, the Lean 5S's were implemented:

1. **Sort** – All tools were removed from sections where it was not regularly used;
2. **Straighten (orderliness)** – Shadow boards were made to indicate the place of each tool;
3. **Shine (cleanliness)** – All sections are cleaned on a daily basis;

4. **Standardise (create rules)** – Daily tool and cleanliness inspections are performed by Team Leaders. Weekly tool and cleanliness inspections are performed within the different sections; and
5. **Sustain (self-discipline)** – Continuous inspections ensure that the cleanliness standard is maintained.

The implementation of the shadow boards cleared the factory of all clutter; these also act as a visual management system to indicate missing tools. As such, this practice reduced the time required for tool inspections, because all tools (or missing tools) were visible at first glance.

#### **4.9.7. Use only reliable, thoroughly tested technology that serves your people and processes.**

At Jonker Sailplanes, new ideas tended to be designed and implemented without testing them first. This led to failure of parts in the field and rework. Furthermore, the factory was often unable to do the rework, because the aircraft are exported. This clearly put the organisation in a bad light. Also, within the manufacturing processes, new processes, products and technology have been used without thoroughly testing these.

This problem is addressed in the following manner: before any new technology is implemented these guidelines are now implemented.

1. Go and see firsthand the value-added work that is performed by the workers in the particular process. Look for new opportunities to eliminate waste and even out the flow.
2. Use a pilot area to improve the process with current technology, equipment and people.
3. Once all the improvements have been made that are possible with the current technology, ask the question if any further improvements are possible with new technology.
4. If it is discovered that new technology can improve the process, the technology is evaluated to ensure that it does not conflict with Jonker Sailplanes's philosophies and operating principles. These include principles of valuing people over technology, using consensus decision-making and an operational focus on waste elimination.
5. If the technology violates these principles or if there is any chance that it may adversely disrupt stability, reliability, and flexibility, the idea is rejected or implementation is delayed until the problem can be solved.
6. If the technology is acceptable, the guiding principle is to design and use it to support continuous flow in the production process and to help employees perform better.

7. When the new technology has been implemented, it is important that should supports the actual work while not distracting people from the value-adding work.

The following guidelines are used before and during the implementation of new technology:

- Use technology to support people, not to replace them;
- A new process should be worked out manually before adding technology to support it;
- When a process works, one should not change it just for the sake of adding new technology, because new technology can be unreliable;
- One should conduct actual test before implementing new processes or technology;
- Also, one should reject or modify technology that is in conflict with the culture of the organisation;
- One should obviously reject technology that could disrupt stability, reliability and predictability; and
- Finally, one should encourage people to investigate the use of new technology if this could increase the flow in the organisation.

#### ***4.10. Let the customer pull value from the producer***

Aircraft are manufactured according to specific customer requirements. Value-adding activities are therefore determined by the customer. The delivery date of an aircraft is also determined by the customer. Thus, when an aircraft is delivered it is done according to customer requirements.

#### ***4.11. Focus on the people in the organisation and the partners outside the organisation***

Employees in the organisation were developed and agreements were made with suppliers of the organisation according to the following Lean principles:

1. Grow leaders who thoroughly understand the work, live the philosophy and teach it to others;
2. Develop exceptional people and teams who follow the company's philosophy; and
3. Respect the extended network of partners and suppliers by challenging them and helping them improve.

The impact of implementing these three Lean principles is discussed bellow:

#### **4.11.1. Grow leaders who thoroughly understand the work, live the philosophy and teach it to others**

Leaders in Jonker Sailplanes need to be grown into leaders that have a combination of experience and the ability to develop, mentor and lead people. Refer to Section 8.5 for recommendations in this regard.

#### **4.11.2. Develop exceptional people and teams who follow the company's philosophy**

Management used to solve all problems and give instructions to workers on how to correct and prevent the problem. This top-down approach needed to be addressed. In order to do this, brainstorming meetings were implemented. Meeting are also now held with all the relevant people involved. Workers from the shop floor have the opportunity to make suggestions and give input regarding the solution.

By using input from the people that perform the work every day, more accurate information is used to make decisions.

While implementing the 20-day cycle, the following situational leadership phases were observed at Jonker Sailplanes:

**Stage 1: Orientation** – During September 2009 the transformation from prototyping to production took place. A 20-day cycle time was implemented. The schedule and the 'rules' were explained to everyone. Everyone was very excited but also very sceptical.

**Stage 2: Dissatisfaction** – After a few months of trying to keep to the seemingly impossible schedule, most people were de-motivated and it required a significant amount of energy from the Production Manager to keep them moving. The employees still needed strong leadership from management and structure as well as social support to get through the tough social dynamics that they did not understand.

**Stage 3: Integration** – After approximately a year the process started to smooth out. Team Leaders started to believe in the system and took charge of implementing improvements to make these even better. The Team Leader and team member began to understand their roles in the larger picture and less support was required from management.

**Stage 4: Production** – After 18 months the production line was running almost smoothly and it was possible to even further reduce the cycle time to 15 days.

### **4.11.3. Respect the extended network of partners and suppliers by challenging them and helping them improve**

Jonker Sailplanes experienced difficulties obtaining parts and material from international suppliers. Due to long lead times, materials are sometimes delivered after these have already expired. The fact that the wrong items are often sent exacerbates the problem. Jonker Sailplanes then has to send these items back and wait once again for the supplier to send the correct items. This obviously causes production delays.

As far as it is possible, local suppliers are used, but not all materials and products are available in South Africa.

Refer to Section 8.7 for the recommendations in this regard.

### ***4.12. Implement with agility***

Once the planning was completed, and the implementation was done accordingly, the different production cells initially had to be managed and monitored closely. This was achieved as follows:

1. Production cells gave daily feedback to the Production Manger regarding any outstanding items on their generic schedules that could not be completed the previous day. This was done one-on-one within each cell (not in the production meeting);
2. The tasks that could not be completed were noted on the Production Delay Form;
3. A root cause analysis was performed in order to determine the reason for the tasks not being completed;
4. Preventative actions were determined to ensure that the problem does not occur again in the future. Throughout the initial phase there were task list of outstanding preventative actions within each cell; and
5. As soon as a resource became available, he was assigned to a cell to assist with these outstanding preventative actions (non-production work).

In order to ensure good communication between the different cells and the Production Manager, a production meeting is held daily between the Production Manager and the Team Leaders. These production meetings were optimised to consist only out of the following discussions:

- Kit shortages;
- Non-conformances; and
- Schedule delays

### **4.13. Become a learning organisation**

Jonker Sailplanes is striving to become a learning organisation by means of the following Lean principles:

1. Go and see for yourself to thoroughly understand the situation;
2. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly; and
3. Become a learning organisation through relentless reflection and continuous improvement.

The impact of implementing these three Lean principles is discussed below:

#### **4.13.1. Go and see for yourself to thoroughly understand the situation**

Decisions used to be made at Jonker Sailplanes without anyone fully understanding the situation. To address this, the Root Cause Analysis process was implemented for all customer complaints, internal non-conformances and Civil Aviation Authority audit findings. By determining and solving the root cause of a problem, other problems are also solved and possibly prevented.

#### **4.13.2. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly**

Meetings at Jonker Sailplanes used to be fairly disordered.

This was addressed by implementing the following guidelines regarding meetings at Jonker Sailplanes:

1. Objectives to the meeting should be clear prior to the meeting (Agenda);
2. The right people should be at the meeting, no one missing and no one else that is not required;

3. Participants in the meeting should be prepared;
4. Effective use of visual aids must be considered;
5. Sharing information should happen as much as possible prior to the meeting so that the focus of the meeting can be on problem-solving;
6. Meetings must start and end on time;
7. Minutes of all meetings must be kept; and
8. An attendance register of all meetings must be kept.

Time was saved by not sharing information during the meeting, but rather focusing on making decisions. By ensuring that only the required people attended a particular meeting, nobody's time was wasted. It is also extremely important to keep minutes of all meetings, because people tend to forget what was said and what was decided.

At Jonker Sailplanes, the culture used to be that when a decision needed to be made, a meeting was held. The first suggestion that was made was normally pursued. This is, however, not always the best solution. Often, meetings were not even held in order to discuss the problem and to decide on a solution; decisions were simply made by one person. The result of such practice is that a decision is taken, but it is changed each time someone hears about it and gives his/her opinion. In the end, the person responsible for executing the decision ends up running between different people trying to find the best solution.

The following decision-making guidelines were implemented:

1. Find out what is really going on by going to the place of the problem and seeing for oneself;
2. Understand the underlying causes that explain surface appearances – ask “why” five times;
3. Broadly consider a few alternative solutions;
4. Compare the different solutions against each other and develop a detailed rationale for the preferred solution;
5. Build consensus within the team, including employees and outside partners (if necessary) by circulating a proposed solution between all the relevant people. Give everyone an opportunity to provide input; and

6. Use efficient means of communication for points 1-5: preferably using one sheet of paper that includes for example the following:
  - Problem
  - Current situation
  - Root cause
  - Alternative solutions
  - Recommended solution
    - Plan
    - Implementation process
    - Time line
  - Cost-benefit analysis.

Following a set procedure when making decisions ensures that no hasty, impulsive decisions are made that could result in production delays and/or financial losses. Building consensus in the team and not only giving orders after a decision has been made, helps everyone to feel part of the decision. This means that employees do not view decisions as orders that were given. Therefore they are more likely to comply. In addition, communication on paper ensures that there is traceability of decisions that were made. Also, when writing something down, one tends to evaluate and consider decisions more thoroughly.

#### **4.13.3. Become a learning organisation through relentless reflection and continuous improvement**

At Jonker Sailplanes there used to be a lack of a problem-solving procedure. In order to address this shortcoming, the following problem-solving guidelines were implemented:

1. A large, vague, complicated problem is discovered;
2. Clarify the problem. Start by observing the situation and comparing it to the standard. In order to clarify the problem, one must go and look where the problem is;
3. Make a first attempt at identifying the point of cause (POC). Asking questions such as “Where is the problem observe?”, or “Where is the likely cause?”, will lead one upstream towards the general vicinity of the root cause, which can be discovered by means of the five-why analysis;
4. Determine root cause by means of five-why analysis;

5. Implement a countermeasure;
6. Evaluate results. Once the results are seen to be effective, these become part of a new standardised approach; and
7. Standardise the new process

After implementing these guidelines, problems could be solved more systematically. Interestingly, it happened that when implementing the second point (comparing the situation to the standard) it was often found that there was no standard. It was clear that this was then the root cause of the problem.

The situation described above relates to The Toyota Way, which involves the following:

1. Learning from one's mistake;
2. Determining the root cause of the problems;
3. Providing effective countermeasures;
4. Empowering people to implement those measures; and
5. Having a process to transfer the new knowledge to the right people to make it part of the company's repertoire of understanding and behaviour.

Jonker Sailplanes implemented a root cause analysis process for all customer complaints and internal non-conformances. The actions that are required are transferred to all the relevant people by means of action lists. Once the root cause has been determined and countermeasures are implemented all procedures are updated to reflect the new knowledge.

By following this process the problem is prevented from occurring again and all new knowledge is captured.

#### **4.14. Pursue perfection**

Once Jonker Sailplanes has streamlined the production flow, the organisation will be able to move from implementing Lean projects to implementing Six Sigma projects.

Six Sigma tools will be used to pursue perfection of the products that are manufactured. However, it is recommended that Six Sigma is only implemented at Jonker Sailplanes in 2013. The impact of implementing this is thus unclear at the moment. In this section, the opinions of Jeff Liker (a Lean expert) and, Rath and Strong (Six Sigma experts) are given regarding the implementation of Six Sigma and Lean.

Liker, being a Lean advocator realises the impact that Six Sigma can have on an organisation: “One very popular program, which General Electric adopted with great success is the Six Sigma, an extension of the Total Quality Management (TQM)” (Liker, 2004:295).

Furthermore, Liker (2004:252) notes that Six Sigma is based on complex statistical analysis tools. There is, however, an example of every Six Sigma tool in use somewhere in Toyota at almost any time. However, it is also true that most problems do not need complex statistical analysis, but instead require painstaking, detailed problem-solving. This requires a level of detailed thinking and analysis that is all too absent from day-to-day activities of many companies. It is a matter of discipline, attitude and culture.

On the other hand, Rath and Strong, being Six Sigma advocates, also advocate the impact that Lean can have on an organisation: “Lean principles and techniques can be used to optimise an individual process or the entire system” (Rath & Strong, 2003:127).

Furthermore, Rath and Strong (2003:127) state the fundamental differences between Lean and Six Sigma: Although both Lean and Six Sigma require a process view of the organisation and involve cross-functional processes, there are some substantial differences between the two:

- Six Sigma employs tools. Lean applies principles.
- Six Sigma tools are used independently of each other. Lean principles are best applied together.

Rath, Strong and Liker not only realised the impact that Lean and Six Sigma can have individually, they also agree that the combination of the two methodologies will have a greater impact on an organisation:

- Six Sigma focuses on improving the value-adding processes, finding the source of the quality problem or downtime and introducing countermeasures to fix it. Lean focuses on the entire value stream and on creating flow among the value-added operations (Liker, 2004:296). Therefore: “There is an obvious case for a harmonious marriage between Six Sigma, which fixes individual processes, and Lean which fixes the connections amongst processes” (Liker, 2004:296).
- “Lean and Six Sigma are perfect complements. Lean focuses on eliminating waste, whereas Six Sigma is concerned with eliminating variation. They have the common goal of making the process both more efficient and more effective’ (Rath & Strong, 2003:127).

However, Liker feels very strongly that these two methodologies should not be placed in competition with each other in an organisation: “In my view, by treating Lean and Six Sigma as two tool kits and then setting up a situation in which different groups in the company go to war over whose tool kit is bigger and better, the company creates a self-defeating improvement program” (Liker, 2004:296).

Liker feels as strongly that the combination of Lean and Six Sigma is not sufficient: “I do not believe Lean tools or Six Sigma tools or a marriage of the two will get a company to a Lean learning enterprise” (Liker, 2004:296). Furthermore: “This is not to say a company should throw out Six Sigma or Lean tools; both are extremely powerful tool kits, but in the end they are just tools. What companies need to be told over and over is that Lean tools represent only one aspect of the broader philosophy of the Toyota Way” (Liker, 2004:297).

In this regard Liker (2003:297) also notes that: “At Toyota it is said that problem solving is 20% tools and 80% thinking. Unfortunately I’ve learned from many Six Sigma programs that some companies get caught up in using all great new sophisticated analysis tools, where problem solving seems to be 80% tools and 20% thinking”.

Both Lean and Six Sigma have been implemented with great success at Toyota and elsewhere. Referring to the above-mentioned expert opinions regarding Lean and Six Sigma, it can be concluded that both methodologies are powerful when applied at the right time in the right place.

On the other hand, both these methodologies can be completely useless if there is a lack of thinking and analysis of the situation. No statistical or analysing tool is more sophisticated than the human brain with its logical thinking ability.

#### ***4.15. Conclusion***

The implementation of the adapted TLS methodology at Jonker Sailplanes was discussed in this chapter. As noted, the impact was overall positive. Where required, recommendations were made for further improvements.

Chapter 5 presents the results and findings that were made after implementing the adapted TLS methodology at Jonker Sailplanes.

## Chapter 5 : Results and findings

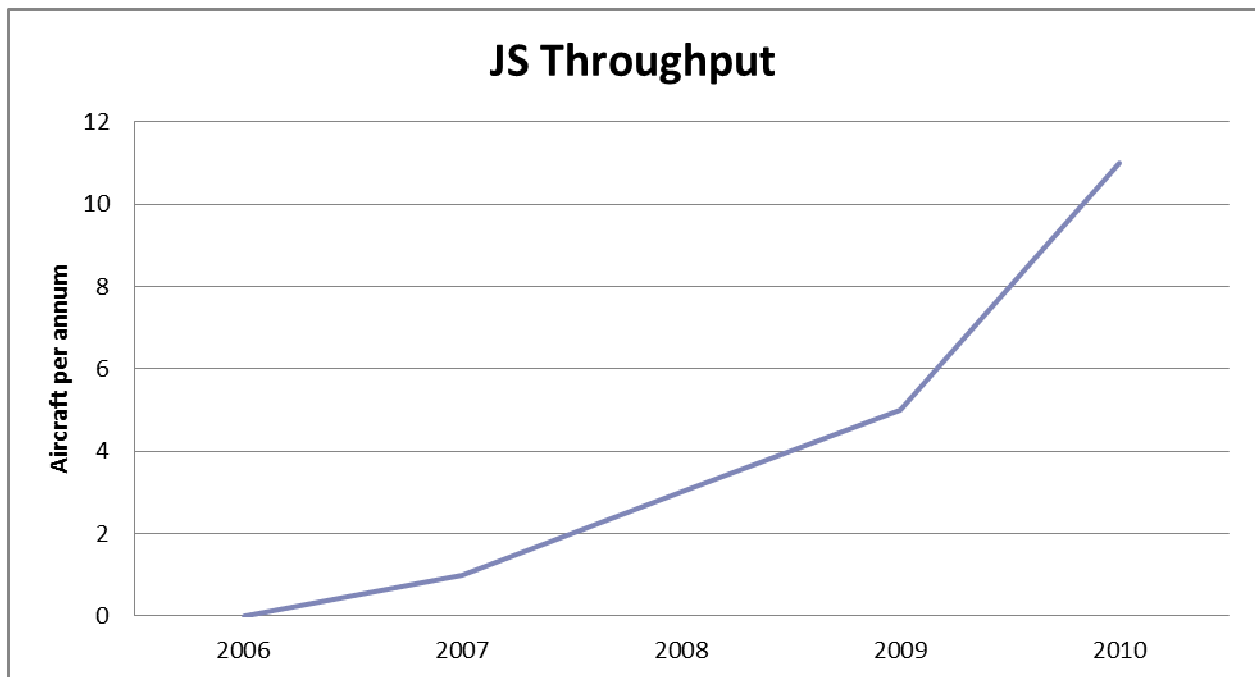
The TLS methodology was followed in order to determine the effectiveness thereof by means of optimising Jonker Sailplanes in terms of the following pre-determined measuring criteria (Refer to Section 1.2):

- Research aim 2.1 - Production tempo (throughput of the organisation); and
- Research aim 2.2 - Increased profit by decreasing operational expenses.

This chapter presents the results according to the pre-determined measuring criteria.

### 5.1. *Production tempo (throughput)*

The number of aircraft that was sold each year increased as shown in Graph 5-1. The incline in sales was steeper after 2009 when TLS was initially implemented.



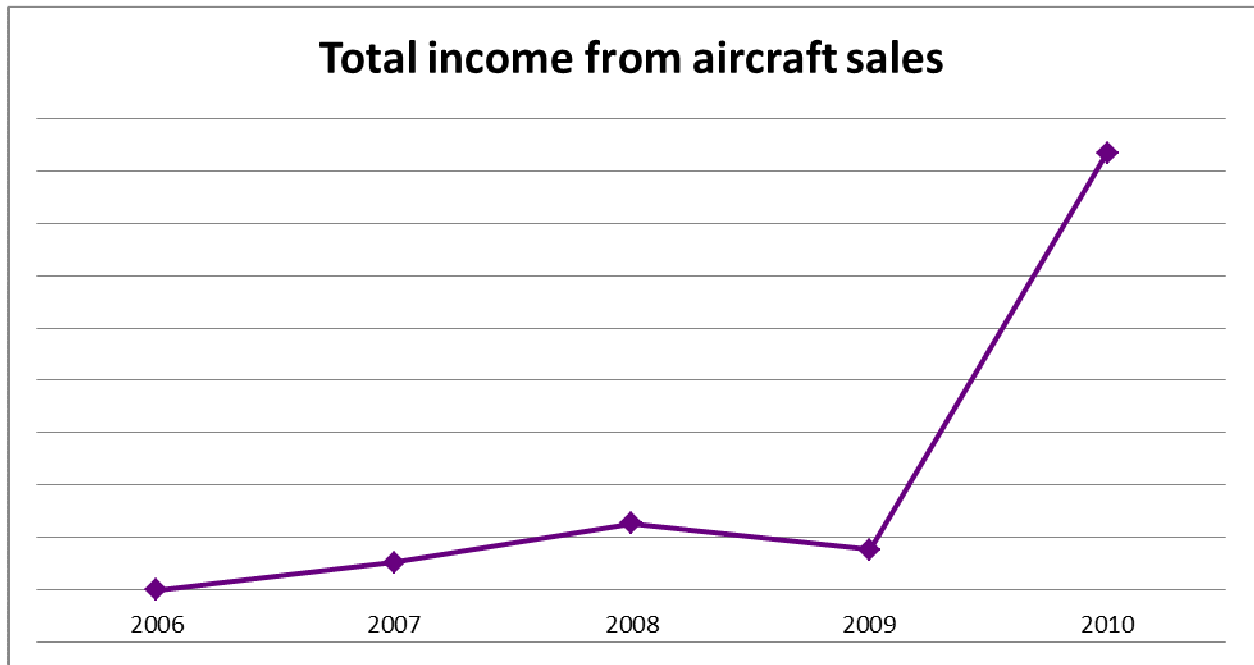
Graph 5-1: Jonker Sailplanes throughput

## 5.2. Organisational profit

The following variables were used to evaluate the change in operating expenses:

- Income from aircraft sales per annum;
- Total expenses per annum; and
- Total salaries and wages per annum

The graphs shown in this section were compiled from financial statements from 2006 - 2010. (note that for confidentiality purposes the actual values were omitted as it is only the trend of the graphs that are of value to this research).

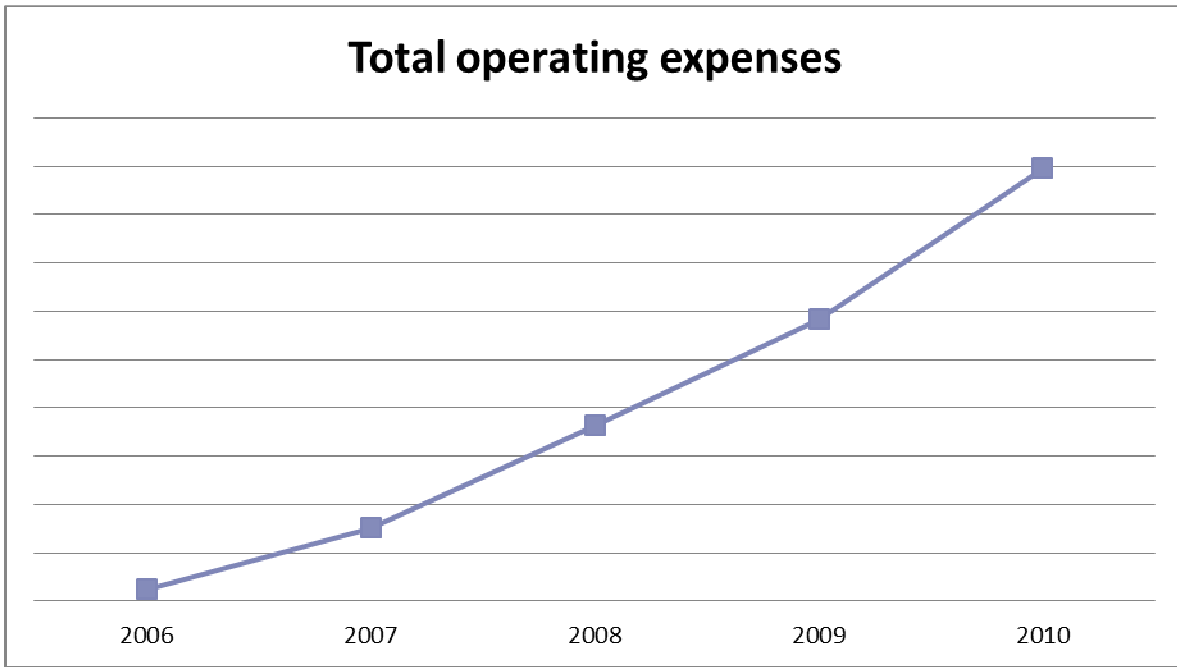


**Graph 5-2: Total income from aircraft sales**

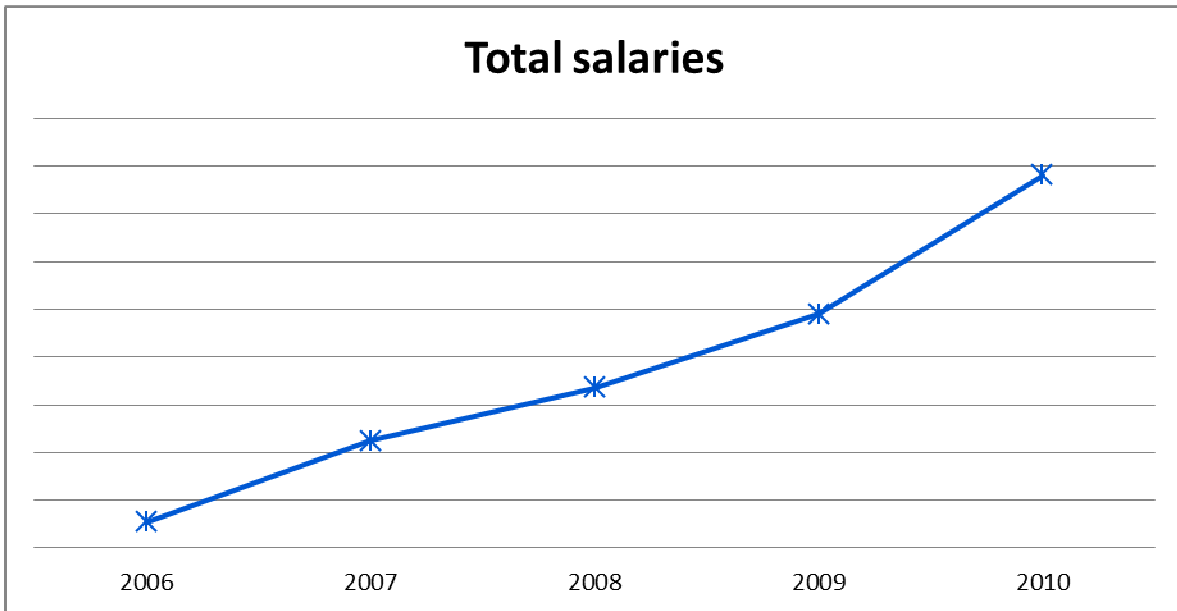
Comparing Graph 5-1 and Graph 5-2, it becomes clear how the income from aircraft sales has increased each year as the number of aircraft that were sold increased. However, in order to establish the effectiveness of the TLS methodology, the decrease in operating expenses needs to be proven.

Referring to Graph 5-3, it is clear that the operating expenses for the factory have also increased as the number of aircraft that were sold, increased. Another parameter that showed an increase was the amount of money that was paid for salaries (Graph 5-4).

Due to the increase in the production tempo each year, an increase in raw material and the number of workers was unavoidable.



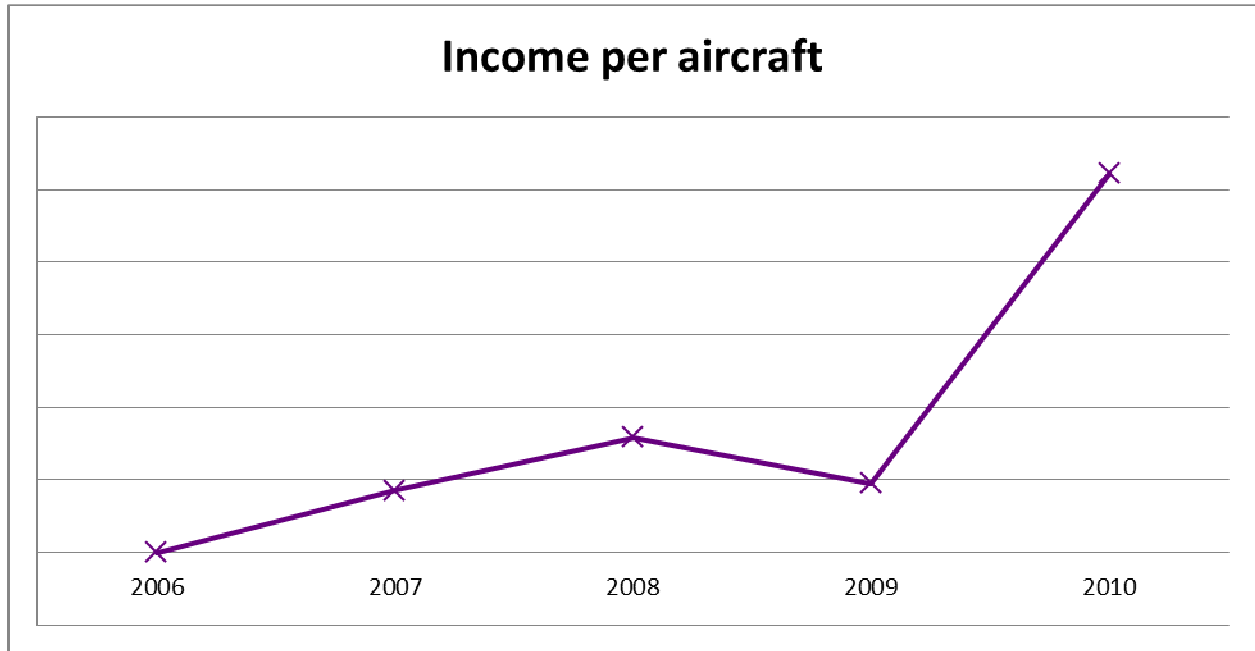
Graph 5-3: Total operating expenses



Graph 5-4: Total salaries

A more applicable indication of the effectiveness of the TLS methodology would be to determine whether the operating expenses increased or decreased per aircraft. Dividing the total income, total expenses and total salaries that were paid by the number of aircraft sold each year would

provide an indication of the operating expenses per aircraft. If the operating expenses per aircraft have decreased, it could be stated that the TLS methodology was effectively implemented at Jonker Sailplanes.



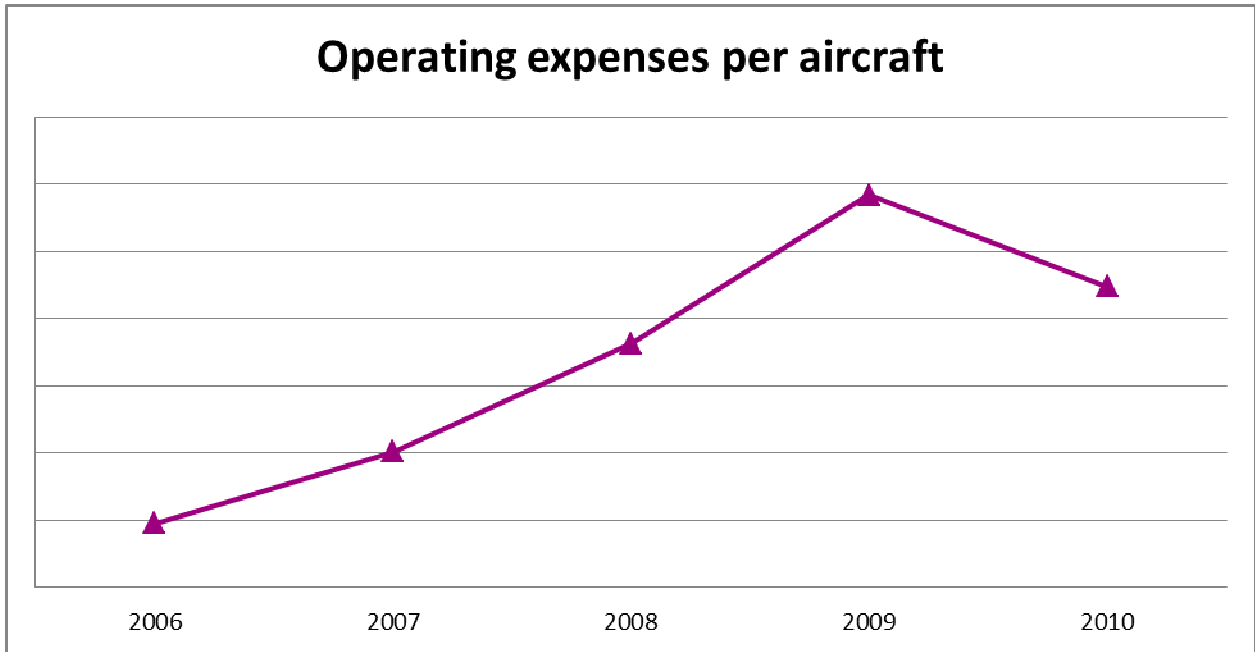
**Graph 5-5: Income per aircraft**

According to Graph 5-5, the income per aircraft has indeed increased. This indicates that the amount of income generated from each sale of an aircraft increased. This increase is irrespective of the operating expenses of each aircraft. The first ten aircraft were sold at a 'special' lower rate because they were part of a limited edition. After the first ten aircraft were sold, the price increased. Although the price (in Euros) remained the same for each aircraft, the amount of income that Jonker Sailplanes receives (in Rand) is dependent on the exchange rate.

Graph 5-6 shows that the operating expenses per aircraft have decreased since TLS was implemented in 2009. This implies that even if the income per aircraft has not increase, the profit would still have increased, due to the fact that the cost of manufacturing an aircraft decreased after 2009.

A verification that the operating expenses have decreased is shown in Graph 5-7 (salaries paid per aircraft). Although the number of workers (and the amount paid for salaries) has increased, the salaries paid to manufacture a single aircraft have decreased. The slight increase in salaries

paid per aircraft manufactured during 2009 can be ascribed to the fact that that the workers had to be employed (and paid for work done) before the aircraft was sold (and income generated).



Graph 5-6: Operating expenses per aircraft



Graph 5-7: Salaries paid per aircraft

### **5.3. Conclusion**

The operating expenses required to manufacture a single aircraft at Jonker Sailplanes have decreased after 2009 when TLS was initially implemented. Therefore, the profit of the organisation has increased and this has shifted the organisation towards reaching *The Goal*. It can therefore be stated that the TLS methodology was effectively implemented at Jonker Sailplanes.

In light of this, the following chapter provides a critical evaluation of the TLS methodology in terms of the predetermined criteria that were set in Chapter 1.

## Chapter 6 : Critical evaluation of the Theory of Constraints Lean Six Sigma methodology

This chapter provides a critical evaluation of the effectiveness of the TLS methodology with regard to the predetermined criteria that have been set in Chapter 1, namely:

- Research aim 1 - The implementation difficulty;
- Research aim 2.1 - The production tempo; and
- Research aim 2.2 - The organisational profit.

### **6.1. Implementation difficulty**

The implementation of any new methodology in an organisation needs to be approached with great sensitivity. Each organisation has its own culture and way of doing things. It is important not to rush into an organisation and 'try to take over their world'. This will only cause resistance from employees as well as management.

Mr Iain Baker (a former Airbus employee and currently a production optimisation consultant for Jonker Sailplanes) had a very significant influence in JONKER SAILPLANES by implementing a great many of the Lean principles. In an interview with Mr Baker, he was asked about the implementation difficulty of the Lean principles within Jonker Sailplanes. He gave the following answer:

*In the case of Jonker Sailplanes, being such a small start-up company, it was both easy and difficult to implement a new methodology:*

*It was easy since it was recognised that there was not a great deal of experience within the organisation and - unlike many growing companies where the owner-proprietors are reluctant to relinquish any control - there was an acceptance of the need to bring in expertise and to introduce changes. As is typical when there is a lack of experience (and so no track record of seeing the impact and benefits of lean processes), there is a level of uncertainty and scepticism of the Lean processes. If a change is partially implemented with poor or incomplete results, then it can be seen that the change itself is poor, and not understood that the implementation was poorly done. Conversely, when processes are*

*properly implemented and do deliver, then scepticism reduces. There is a continuous balancing between the extremes of directing process change in a highly proscriptive manner (which limits people engagement) and giving light guidance (which can lead to slow rates of progress and errors in implementation).*

*The difficult part of the implementation is the continued need to change the culture of the organisation. With the starting point of a technically inspired dream, the organisation has grown into a business with different demands and expectations. Although the underlying technical excellence is still a core value, at times it has to be compromised or given a lower priority for business requirements - and with a lack of business experience this can cause conflicting opinions. Such conflicts could be greatly reduced by agreeing a company business plan and exposition but to date there had been little effort placed on this need (Baker, 2009).*

Concurring with Mr Baker, it can be stated that implementing TLS was much easier once the results have become apparent. The most difficult part of implementing TLS was changing the culture of the organisation. Since it was a small organisation driven by such passionate individuals, conflict sometimes existed between following the dream and managing an organisation.

Furthermore, when implementing an improvement project, it is often difficult to decide where to begin within the organisation. The TLS methodology was designed in such a way that it addresses this difficulty. By following the TOC methodology, the constraint was identified and thus indicating the starting point of the improvement project at Jonker Sailplanes. After identifying the constraint, the Lean methodology provided guidance regarding how to improve the constraint and the rest of the organisation. Thus, the TLS methodology identifies the one single area within an organisation that can be improved that will have the most significant effect on the entire organisation. Lean principles also helped to manage all the changes that took place by means of visual management. This ensured that there were few surprises, since nothing was hidden.

Implementing TLS is uncomplicated since it is a logical, systematically, step-by step methodology. It creates a calmer and more organised working environment. There are few surprises, because no problems are hidden.

## **6.2. Production tempo (throughput)**

The JS1 Revelation prototype had its maiden flight in December 2006. After the maiden flight, the number of aircraft sold increased each year (see Graph 5-1).

It is clear that the throughput has increased exponentially after TLS was implemented in 2009. It is also important to note that the increase in the production tempo was not simply a once-off improvement that caused the annual throughput to increase once into the following year. Rather, one can see a continuous increase from 2009 to 2010 and again to 2011. This increase in throughput is expected to continue year after year once Six Sigma has also been implemented.

Thus, it can be stated with confidence that the TLS methodology was highly effective in increasing the throughput of Jonker Sailplanes.

## **6.3. Organisational profit**

The profit of an organisation is determined by the following equation:

$$\text{Price} - \text{Cost} = \text{Profit}$$

Referring to Section 1.1, profit can only be increased by decreasing the cost of the product (operating expenses). The following variables were used to evaluate the change in operating expenses:

- Income from aircraft sales per annum;
- Total expenses per annum; and
- Total salaries and wages per annum.

Referring to the findings discussed in Section 5.2, it is clear that the implementation of TLS at Jonker Sailplanes has led to an increase in organisational profit each year. The operating expenses are expected to decrease even more after Six Sigma has been implemented, since this methodology will reduce variability of the output of process and increase the quality of the product. Thus, Six Sigma will help to pursue perfection.

#### **6.4. *Critical evaluation conclusion***

Overall, the implementation of TLS at Jonker Sailplanes was a success. The production tempo (throughput) and the organisational profit have both increased. This was achieved while the implementation of the methodology was done with relative ease.

## **Chapter 7 : Discussion and interpretation**

During the course of implementing the TLS methodology at Jonker Sailplanes, a number of observations were made regarding the organisation's transition from prototyping to production, the implementation sequence of Lean and TOC, the starting point of the continuous improvement project, and the identification of the constraint in the organisation. These observations are discussed in the current chapter.

### ***7.1. From prototyping to production***

Initially, the manufacturing of the entire aircraft was completed in one hanger and the focus of the organisation was on prototyping (see Figure 7-1). After the first few aircraft were completed, the organisation's focus shifted from prototyping to production, and a production line set-up was developed in which the work flowed from one production stage to the next. Consequently, the work required to manufacture an aircraft was divided into 20-day production stages. This implied that the aircraft would spend 20 days in a production stage in which all the allocated work had to be completed. After 20 days the aircraft would then proceed to the next production stage.

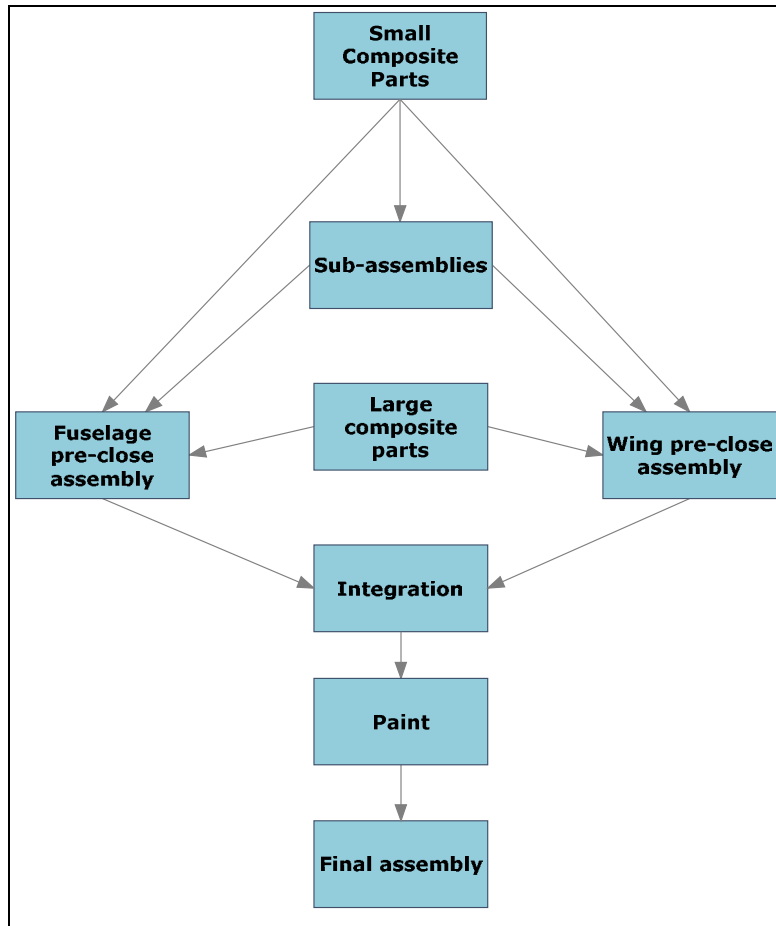
The 20 working day cycles were implemented in August 2009. During February 2011, the cycle time was further reduced to 15 working days.



**Figure 7-1: Manufacturing done in one hanger**

The production line that was set up required more floor space. Therefore, during 2009 Jonker Sailplanes expanded their facilities into a second hanger. The facility began to develop into a production line with separate production cells responsible for specific allocated tasks within their production cells.

A Team Leader manages each production stage to ensure the quality of the work; he also has to ensure that the deadlines are met. Figure 7-2 shows how the parts and assemblies flow from one production stage to the next.



**Figure 7-2: Jonker Sailplanes production line**

The manufacturing of an aircraft starts with the building of the small composite parts (see Figure 7-3). These composite parts are assembled into sub-assemblies, for example the wheelbox sub-assembly, airbrake box sub-assembly, wing root rib sub-assembly and so forth.

The large composite parts that are manufactured comprise the skins for the wing and fuselage pre-close assemblies as well as assemblies such as the tailplane, rudder, elevator and flapperons.



**Figure 7-3: Production line developing - Small Composite cell**

The fuselage and wing pre-close assemblies consists of two skins each (fuselage left and right skin and the wing bottom and top skin) together with small composite parts and sub-assemblies.

The pre-close assemblies are done by building small composite parts and sub-assemblies into one of the skins (see Figure 7-6). The parts and sub-assemblies are only bonded into the one skin (fuselage left skin and wing bottom skins). Once all the parts and sub-assemblies have been bonded in, bonding flox is applied on all the bonding surfaces. The other skin (fuselage right skin and wing top skin) are then bonded onto the first skin, into which the parts and sub-assemblies were initially bonded (see Figure 7-4 and Figure 7-5). Once the two halves (skins) are bonded together and joined, these are considered to be one part and cannot be opened again; thus the name, “pre-close assembly”.



Figure 7-4: Closing the wing moulds



Figure 7-5: Closing the fuselage moulds

If any non-conformances are hereafter detected in the wing, a hole needs to be cut into the skins and repaired afterwards. Before closing the assemblies, thorough inspections are conducted in order to ensure that all controls are operational, no tools are left inside the assembly and that all parts and sub-assemblies are bonded in the correct positions.



**Figure 7-6: Production line developing – Wing Pre-close Assembly cell**

Once the wings and fuselage have been built, they need to be integrated in order to ensure a perfect fit and to ensure high-quality aerodynamic performance. The controls need to be set up to ensure that they are operational and that they have been produced according to design.

After the integration process, the surface finishing of the aircraft needs to be done (see Figure 7-7). Paint is sprayed on and then sanded until the surface is smooth and scratch-free. After this production stage the aircraft needs to be protected from any scratches or damage.



**Figure 7-7: Production line developing - Jonker Sailplanes spray booth**

The only work that remains after the aircraft has been painted is to install the cockpit parts that have been sprayed individually, as well as a few final touches to the controls. This is done during the Final Assembly Stage (see Figure 7-8). Once the Final Inspection has taken place and all the other paperwork has been completed, the aircraft is test flown.



**Figure 7-8: Production line developing - Final Assembly cell**

On 4 June 2010, Mr. Baker did a presentation at Jonker Sailplanes to the employees and management to show the transition that took place within Jonker Sailplanes. Figure 7-9 is one of the slides that he showed and it clearly indicates the radical change that took place in Jonker Sailplanes

## JS – The Winning Formula



June 2009



May 2010



- Remember always needing parts, and losing tools ???
- Transition from 'hobby shop' to aircraft production line
- Parallel production, cellular manufacture
- Design & manufacture processes now best in the world
- Five gliders delivered in last six months, more than whole of 2009

04-Jun-10

**Figure 7-9: Transition in Jonker Sailplanes**  
(Baker, 2009)

### ***7.2. Implementing Lean before TOC***

Initially, Jonker Sailplanes started to implement Lean before TOC. This created numerous problems, due to the fact that Lean focuses on a company as a whole. Lean was introduced to the different production cells simultaneously and each cell implemented it in a slightly different manner. It was noted that Lean had more success in some production cells than in other. Some of the Team Leaders understood it better and jumped at the opportunity for improvement. These Team Leaders showed enormous improvements: they reduced their cycle time by days (and later weeks) and their quality increased.

However, in the process, the stronger resources (those with higher capacity) were becoming stronger and the weaker resources were becoming weaker relative to the others. Consequently, the stronger resources kept on “running away” from the weaker ones. The gap between the

marching soldiers was steadily increasing and inventory kept on growing. In Jonker Sailplanes's case, the stronger resource (Composite Cell) was in front of the constraint. It was therefore easy for the strongest resource to keep producing inventory, because it was not held back by the constraint.

A reason for the weaker resources not being able to catch up after implementing Lean is that Lean takes time to implement. The different Team Leaders were responsible for implementing their own ideas and improving their own cells. This took time away from their available time to do their allocated production work. The constraints were the production cells with the least available time. Therefore, these cells did not have extra time available to plan and implement Lean ideas. Ironically, the constraints were so busy attempting to keep up with the rest of the factory that they did not have time to implement ideas that could – in the long run – help them keep up.

The conclusion that was reached is that implementing Lean before TOC constitutes a high risk for a plant. In this case it did not increase throughput because the throughput was still blocked by the constraint. Neither did it decrease the amount of inventory - it actually increased it, because the length of the line of marching soldiers increased. Implementing Lean first increased operating expenses, because of the extra overtime that the constraints had to work in order to keep up and because of the excess inventory that was creating.

A further conclusion that was arrived at, given the above discussion, is that Lean might have actually moved the company away from *The Goal* instead of towards it.

It was only after TOC was implemented and the constraint had been identified, that the focus and energy were directed towards the appropriate place. An organisation can only produce as fast as the constraint is producing. Until the constraint is optimised, all other improvements are worthless with regards to the organisational throughput.

### ***7.3. Starting point of the continuous improvement project***

When implementing a continuous improvement project, it is difficult to decide where to start. Should the project start at the end of the assembly line where all the problems accumulate? When, for example, problems are identified in Final Assembly, the root causes can be investigated and solved in the preceding cells.

Another approach would be to start at the beginning of the production line and to improve each cell, from the first to the last. By following this approach, the problems of the preceding cell would be solved before the next cell is improved, thus reducing the number of problems in the receiving cell.

The problem with both these approaches is that the process would not start at the point that would have the greatest impact on the entire organisation. When implementing a new idea within an organisation, it is important to see results fairly soon after implementation. This is required to keep the employees and role-players motivated in order for the project not to lose momentum.

In other words, when a large amount of energy is invested towards making improvements in a specific area, and the results do not justify the amount of energy that invested, employees will lose faith in the project and start doing the bare minimum that 'Management' requires. The problem with this paradigm is that any production improvement project would fail if it only involved Management, since the workers are actually doing the value-adding work. Management is only a support system for them to do the value-adding work that produces the income.

When implementing a project in an organisation the amount of energy that is invested tends to decrease over time. This is another reason why the initial energy should be directed towards the place of highest impact.

TOC provides the answer to this question by identifying the resource that should be optimised first. An organisation can only perform as fast as its slowest worker. Therefore, improving any other resources than the one with the lowest capacity will have no effect on the overall performance of the organisation. The entire TOC theory is built around the constraint and the improvement thereof. If the organisation succeeds in improving the soldier who marches the slowest, the organisation as a whole will continuously march faster.

#### **7.4. Identifying the constraint at Jonker Sailplanes**

According to Goldratt's TOC, a constraint is identified by a heap of inventory in front of it. In the case of Jonker Sailplanes, it was difficult to identify the Wing Pre-close Assembly as the constraint, because there was no heap of inventory in front of it. This can be ascribed to a phenomenon called *jig-lock* (Coetzee, 2011).

This phenomenon occurs when there are not enough moulds/jigs to produce parts as fast as the next production cell requires it. Jonker Sailplanes only has one set of wing moulds. While the Pre-close Assembly is utilising the wing moulds, it is not possible to build the next pair of wing skins. Therefore, there were never wing skins waiting for processing in front of the Wing Pre-close Assembly.

Also, metal parts were built in batches and kept in the metal store; therefore excess inventory was not visible in front of Wing Pre-close assembly. Furthermore, composite parts were manufactured on demand according to the kitting system, Since Wing Pre-close Assembly were behind schedule, they did not require any parts and therefore none were manufactured. Therefore, there was not a heap of composite inventory in front of Wing Pre-close Assembly.

It could be concluded, however, that Wing Pre-close Assembly themselves were preventing a heap of inventory of accumulating in front of the cell.

#### **7.5. Conclusion**

Interesting and insightful observations have been made during the implementation of the TLS methodology at Jonker Sailplanes. These observations were discussed during the course of this chapter.

After studying the impact that TLS had on Jonker Sailplanes together with the observations, results and findings, recommendations will be presented towards the further improvement of this sailplanes-manufacturing organisation. These recommendations are noted in the next chapter.

## Chapter 8 : Recommendations

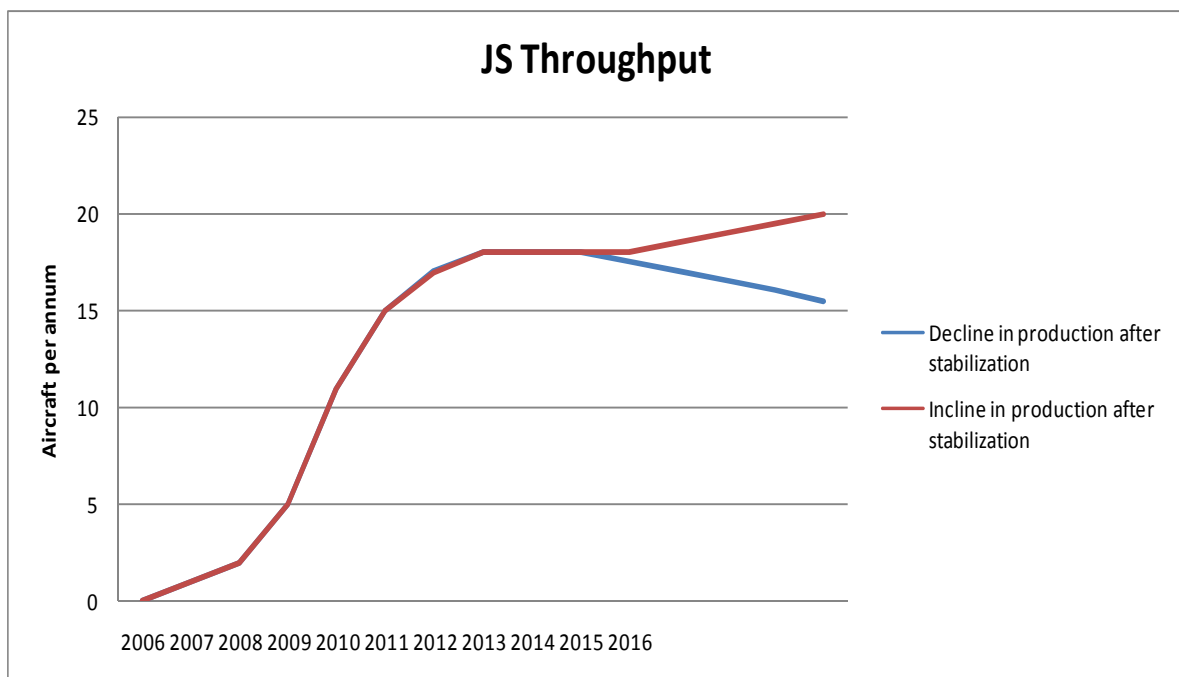
The following recommendations are made for Jonker Sailplanes for further improvements after the TOC Lean Six Sigma methodology was implemented in the organisation.

### 8.1. Recommendation 1 – Long-term vision

Jonker Sailplanes needs to develop a long-term vision. All shareholders should agree on what the objective(s) of the organisation are. They should decide what the immediate goals are as well as the medium-term and long-term goals. The vision of the organisation should constitute the vision for each of the following areas within the organisation:

- Product development;
- Employee development (human resources);
- Responsibility towards the community; and
- Organisational growth.

### 8.2. Recommendation 2 - Implementing Six Sigma



**Graph 8-1: Jonker Sailplanes throughput forecast**

During 2011, the throughput began to stabilise at 15 aircraft per annum. After such stabilisation has been achieved, one of two scenarios can occur: the number of aircraft produced per annum can increase or either decrease. The natural human tendency will be to fall back into a relaxed atmosphere causing the production rate to decrease.

In order to prevent the latter option from occurring at Jonker Sailplanes, it is recommended that Six Sigma should be implemented in 2013 as part of ongoing research. This will ensure an increase in throughput instead of the natural decrease.

### ***8.3. Recommendation 3 – Metal kitting system***

Metal parts are manufactured by Jonker Sailplanes and then sent to an aircraft welder. After a week the parts return from the welder and are then sent for plating. After another week the parts return to Jonker Sailplanes and are ready to be kitted and assembled into the aircraft. Due to these long lead times, metal parts are manufactured in batches of three.

Therefore, Jonker Sailplanes experiences difficulty with the metal parts stock management. It is not clear at any given point in time how many parts are available and which parts will cause kitting shortages. Only when the Kitting Coordinator needs a part in order to complete a kit, is it realised that the part was never manufactured. These problems are hidden by excess inventory and can therefore not be prevented in advance. Furthermore, due to the batching of three sets of parts, the excess inventory will always be in the store. Therefore it needs to be visually managed in order to anticipate and prevent kitting shortages.

It is recommended that the metal store should be replaced with a kitting area. Kit containers can be stacked in sets of three. A kit list is placed in each container that shows the desired and actual contents of each kit at any given time. When completed batches of three parts have been received, each part should be placed in a kit container and marked off on the kit list.

By following this triple kitting method, the focus is shifted from managing the inventory that is available to managing the parts that are not available. It is a visual management system that exposes problems.

#### **8.4. Recommendation 4 – Group Leaders**

Jonker Sailplanes has a very flat hierarchy structure. There is only one Production Manager who manages nine Team Leaders. The Production Manger is tasked with solving all the day-to-day problems.

A general problem is that the subject matter experts are caught up in day-to-day production activities that they have to perform themselves due to a lack of other qualified employees. This prevents them from improving manufacturing process and duplicating their skills and knowledge to other employees.

Jonker Sailplanes needs to construct a more vertical hierarchy and appoint group leaders in between the Production Manager and the Team Leaders. subject matter experts needs to be released from day-to-day activities and appointed in a more supervisory position as Group Leaders. They should also be part of the *andon* system in order to assist team members with day-to-day obstacles. The Production Manager should only be doing higher level work, such as scheduling and planning. Additionally, subject matter experts should be utilised during problem solving brainstorming meetings.

During March 2011, the schedule was reduced from a 20-day cycle time to a 15-day cycle time, which points to an increase in output concurrent with new demands on human resources. According to Liker (2004:192), it would be inhumane to not appoint Group Leaders. They need to act like on-the-spot helpers, ready to jump in any time there is a problem, such as when there is a call for help through the *andon* system. The Group Leader also needs to be a safety valve, walking the line and watching to see if there are any problems emerging, such as parts running low in numbers or someone falling behind schedule and needing assistance or relief. No one should be left alone to figure it out for themselves.

Furthermore, an *andon* chord system should be put in place which would allow Team Leaders and team members to focus on performing their allocated tasks instead of performing problem-solving tasks. This can, however, only happen once Group Leaders have been appointed to deal with problems that emerge – these Group Leaders should then ensure that preventative actions are implemented. One suggestion is to make use of the Subject Matter experts – if they are

appointed as overseeing Group Leaders, they will have a greater influence within the organisation. Consequently, the quality of parts and assemblies will increase.

At Jonker Sailplanes the current responsibilities of the Team Leaders and Group Leaders are divided differently than what is proposed by Toyota. In Table 8-1, the X's indicate the responsibilities as proposed by Toyota and how the responsibilities are currently divided at Jonker Sailplanes. The X's in brackets should be reallocated to either the Group Leaders or the Team Leaders (as indicated).

**Table 8-1: Roles and responsibilities at Toyota vs. Jonker Sailplanes**

	At Toyota, performed by		At Jonker Sailplanes, performed by		
	Team Leader	Group Leader	Team Leader	Group Leader	Production Manager
Meet production goals	X				(X) Team Leaders
Respond to <i>andon</i> calls by team members	X				(X) Group Leaders
Confirm quality – routine checks	X				(X) Group Leaders
Cover absenteeism	X		X		
Training and cross-training	X		X		
Work orders for quick maintenance	X				(X) Team Leaders
Ensure standardised work is followed	X				(X) Team Leaders
Facilitate small group activities	X				
Ongoing continuous improvement projects	X				(X) Team leaders
Insure parts/materials are supplied to process	X				(X) Team Leaders
Manpower / vacation scheduling		X			X
Monthly production planning		X			(X) Group Leaders
Administrative: policy, attendance, corrective actions		X			X
<i>Hoshin</i> planning		X			(X) Group Leaders
Team morale		X			(X) Group Leaders
Confirm routine quality and team leader checks		X			(X) Group Leaders
Shift to shift coordination		X	X		
Process trails (change in process)		X			(X) Group Leaders
Team member development and cross-training		X			(X) Group Leaders
Report / track daily production results		X			(X) Group Leaders
Cost reduction activities		X			(X) Group Leaders
Process improvements projects: productivity, quality, ergonomics, etc		X			(X) Group Leaders
Coordinate major maintenance		X			(X) Group Leaders
Coordinate support from outside groups		X			(X) Group Leaders
Coordinate work with up-stream and down-stream processes		X			(X) Group Leaders
Group safety performance		X			(X) Group Leaders
Help cover team leader absence		X			(X) Group Leaders
Coordinate activities around major model changes		X			(X) Group Leaders

### **8.5. Recommendation 5 - Leaders**

Many of Jonker Sailplanes' managers are 'taskmasters' - managers who are experts in their areas, but have a top-down approach and who are lacking in people skills. They tend to treat employees as puppets; this is very dangerous, because one wrong pull of a string can cause everything to collapse. They are also distrustful of others with less experience. They might issue orders, but would add precise instructions on how to perform the job: they tend to micro-manage.

Leaders in Jonker Sailplanes need to be grown into leaders that offer a combination of experience and the ability to develop, mentor and lead people. They will then be respected for their technical knowledge and followed for their leadership abilities. They must seldom give orders; they should rather lead and mentor through questioning. They need to ask questions about the situation and the person's planned approach, but they must not give answers (even if they feel that they have all the knowledge).

### **8.6. Recommendation 6 – Employee motivation**

Jonker Sailplanes does not really focus on the basic needs or the higher-level needs of the employees, particularly with regard to employee motivation. There is no active motivational policy within Jonker Sailplanes. A variable salary scheme was implemented by means of which employees could earn more money when the production schedule was beaten, but it also penalised the workers when any slippage of the production schedule occurred. It was once again confirmed that money is not a motivator. The variable pay scheme created conflict and unhappiness, and management was accused of stealing the workers' money. It did more harm to the workers than motivate them.

Different people are motivated in different ways. A good employer will find the way that best motivates individual employees and keep them motivated in this manner. It is recommended that the motivational policy as set out below should be considered by Jonker Sailplanes. By following this policy, all the employees will be motivated in their own 'motivational language' that they understand.

### **1. The basic needs of the worker need to be satisfied**

When a worker comes to work hungry or upset due to problems at home, he cannot focus on the work that is expected from him. He will make unnecessary mistakes that will cost the company money and that could put people's lives in danger. The organisation needs to put a system in place where the workers can talk to a trusted counsellor in the organisation, in order to see if the organisation can assist them in any way. This must, however, not be seen as an excuse not to perform his duties and responsibilities. If the organisation cannot assist the worker directly with his problem, the counsellor should support him in managing the problem.

### **2. Jobs need to be enriched so that they are “intrinsically” motivating**

Employees need to receive feedback regarding their performance on a regular basis. Furthermore, employees need to know in which areas of their jobs and personalities they can improve. It follows that both the employees as well as the organisation can benefit from having improved employees. People who have matured enough in their positions need some degree of independence. Once an employee has proven himself, he must not feel as if he is being checked upon.

### **3. Employees need to be motivated by means of incentives**

Clear standards should be provided to employees. They must be taught the most effective way of achieving these standards, and then the organisation should award bonuses when employees exceed the standards that have been set. The standards need to be clear, determined in advance and based on quantity, not quality.

### **4. Behaviour modification**

Rewards and punishments are used to motivate employees. There are many things that employees find rewarding and punishing, apart from money. Examples are praise from a supervisor or winning an award. It is important that the positive or negative reinforcement comes as quickly as possible after the action.

### **5. Goal setting**

Employees are motivated by challenging but attainable goals. They need to be measured according to their progress towards these goals. A sense of accomplishment needs to be created within each employee.

It is recommended that all the above-mentioned motivational policy is implemented at Jonker Sailplanes in order to ensure that each employee is motivated according to his need.

### **8.7. Recommendation 7 - Suppliers**

Jonker Sailplanes can only improve as fast as their suppliers are supplying. In order for Jonker Sailplanes to remain in *The Race*, the organisation will have to build relationships with their suppliers and assist them towards improving. The suppliers should be motivated by setting challenging goals for them and then helping them achieve it. In some cases, Jonker Sailplanes will have to go to the supplier's facility and help them to become a Lean organisation.

Good relationships of trust need to be established with all suppliers in order for the procurement process to be improved.

### **8.8. Recommendation 8 – Visual management**

When walking into a production cell at Jonker Sailplanes, it is not currently possible to see at first glance if the cell is on schedule or behind schedule. It is not clear, either, if the cell needs assistance in solving any problems. Neither is it clear what the cell's goals are and whether or not they are achieving these.

In order to address this problem, visual management needs to be improved within each cell. This will ensure that a cell is transparent and that it is a waste-free environment. Visual management will also ensure that problems are not hidden and can therefore be managed.

The whiteboards in each cell should clearly show the following information:

- The cell's generic schedule that is updated daily in order to show whether or not a cell is on schedule;
- The date when the next kit is required;
- Any difficulties that are experienced and with which the cell needs assistance;
- A list of items that need to be implemented in order to improve the production tempo (continuous improvement); and
- The reasons for any production delays should clearly be indicated in order for the problems to be solved.

### **8.9. Recommendation 9 – Non-conformances**

The number of internal non-conformances that occur needs to be addressed. After a non-conformance has been raised regarding a part, it is either scrapped or reworked. Extra time is required from the engineering department to decide on the most appropriate corrective actions to follow, and extra time is required from the builder to rework the part.

Training for composite and metal part builders also needs to be improved. Additionally, tools, moulds and jigs that are used need to be improved in order for the part to be built right the first time.

### **8.10. Recommendation 10 – Teamwork**

The notion of teamwork cannot be over-emphasised: “Never before in the history of the workplace has the concept of teamwork been more important to the functionality of successful organisations. Social and technology changes are occurring more rapidly than ever. As a result, organisations are under increasing stress and must adapt quickly to remain competitive. No longer can we depend on a few peak performers to rise to the top to lead. If we are to survive, we must figure out ways to tap into the creativity and potential of people at all levels” (Blanchard *et al.*, 2000:1).

Teamwork needs to be improved at Jonker Sailplanes, especially in the larger cells. Also, Team Leaders need to understand their roles and responsibilities. At the same time, team members need to find their place in the team. Consequently, all employees need to understand their strengths and weaknesses. They also need to understand each other’s strengths and weaknesses and how to work together to get the best results as a team.

Employees should consider participating in team-building activities that will strengthen them as a team. Interrelation skills need to be developed by means of workshops.

These activities and workshops will increase the understanding of each other between team members and Team Leaders.

### ***8.11. Conclusion***

Although very significant improvements were observed after implementing the TLS methodology at Jonker Sailplanes, the above-mentioned recommendations will ensure even greater improvements in the future.

## List of references

BAKER, I. C. 2009-2011. Various verbal discussions and inputs given.

Former responsibilities:

- Airbus SAS Employee, Toulouse France. Controller – Head of Inventory Performance / Head of Inventory Controlling
- Airbus UK (& BAE SYSTEMS - Airbus & British Aerospace Airbus Ltd), Filton UK  
Strategic Value Based Management Analyst
- British Aerospace Airbus Ltd, Filton UK  
A340-500/600 Project Planning Manager
- Raytheon (previously British Aerospace) Corporate Jets Ltd, Hatfield UK  
Project Design Manager
- British Aerospace Inc, Herndon VA USA  
System Engineering Manager

BLANCHARD, K.H., 2000. *The one minute manager builds high performance teams*. New York:HarperCollins Publishers. 112p.

BRITZ, A.G. 2008. *Six Sigma: A framework for successful implementation in South Africa*. Potchefstroom: NWU. (Dissertation – MBA). 102p.

Coetzee, G.J. 2010. Various verbal discussions and interviews. Jonker Sailplanes Production Manager (Former Denel Aviation Product Line Manger).

GEORGE, M. O. 2010. *The Lean Six Sigma guide to doing more with less*. New Jersey: John Wiley & Sons, Inc. 318p.

GOLDRATT, E. M. & COX, J. 1992. *The Goal*. New York: North River Press, Croton-on-Hudson.

GOLDRATT, E. M. & FOX, R. E. 1986. *The Race*. Great Barrington: North River Press. 179p.

JIN, J., ABDUL-RAZZAK, H., ELKASSABGI, Y., ZHOU, H., HERRARA, A. 2009. *Integrating the Theory of Constraints and Six Sigma in Manufacturing Process Improvement*. World Academy of Science, Engineering and Technology. 49:550-554.

JORDAN, J.A. & MICHEL, F.J. 2001. *The lean company: making the right choices*. Dearborn, MI: Society of Manufacturing Engineers. 334p.

LIKER, J. K. 2004. *The Toyota way*. New York: McCraw-Hill. 310p.

PIRASTEH, R.M. & FARAH, K.S. 2006. The top elements of TOC, Lean, and Six Sigma (TLS) make beautiful music together. *APICS Magazine*. May 2006.

RATH & STRONG / Aon Management Consulting. 2003. *Six Sigma leadership handbook*. New Jersey: John Wiley & Sons, Inc. 566p.

WOMACK, D, Jones, P, Roos, D. 1991. *The Machine that changed the world: The story of Lean production*. HarperPerennial

### **Internet sources consulted:**

- Basic Knowledge Source:  
[http://www.businessknowledgesource.com/manufacturing/what\\_is\\_a\\_sipoc\\_diagram\\_high\\_level\\_process\\_map\\_and\\_how\\_is\\_it\\_used\\_in\\_six\\_sigma\\_021699.html](http://www.businessknowledgesource.com/manufacturing/what_is_a_sipoc_diagram_high_level_process_map_and_how_is_it_used_in_six_sigma_021699.html).  
(Accessed 20 April 2011)
- Carpenter Group LLC:  
<http://www.quality-improvement-matters.com/project-charter.html#business-case>.  
(Accessed 20 April 2011)
- Corporate Coach Group  
<http://www.corporatecoachgroup.co.uk/blog.asp>. Author: Chris Farmers.  
(Accessed 25 April 2011)
- DMAIC Tools:  
<http://www.dmaictools.com/dmaic-measure/grr> (Accessed: 27 April 2011)

- DRM associates:  
<http://www.npd-solutions.com/voc.html>. Author: Kenneth Crow. (Accessed: 20 April 2011)
- Educate virtually:  
[http://educatevirtually.com/post/ctq\\_tree\\_its\\_all\\_about\\_what\\_to\\_measure/](http://educatevirtually.com/post/ctq_tree_its_all_about_what_to_measure/)  
(Accessed: 27 April 2011)
- Elite Consulting:  
[http://www.elite-consulting.com/six\\_sigma\\_tools.htm](http://www.elite-consulting.com/six_sigma_tools.htm). (Accessed 20 April 2011)
- Lean Plus  
<http://www.leanplus.com/casestudies/index.htm>. (Accessed 25 July 2009)
- MIC Quality: Six Sigma glossary  
[http://www.micquality.com/six\\_sigma\\_glossary/control\\_charts.htm](http://www.micquality.com/six_sigma_glossary/control_charts.htm)  
(Accessed: 27 April 2011)
- The Lean enterprise: value stream mapping.  
<http://www.nwlean.net/toolsCD/VSM/4%20steps%20to%20VSM.pdf>.  
(Accessed: 28 March 2011)
- World Class Manufacturing:  
<http://world-class-manufacturing.com>. (Accessed: 26 April 2011)

## Reading List: Recommended sources

- **Theory of Constraints**

GOLDRATT, E. M. *Critical chain – Project management*

GOLDRATT, E. M. *It's not luck – Sequel to The Goal*

GOLDRATT, E. M. *Theory of constraints – A walk through the crucial stages of a continuous improvement program.*

- **LEAN**

WOMACK, J.P. & JONES, D. T. (1996) *Lean Thinking*, Banish waste and create wealth in your corporation. Bath: The Bath Press. 350p.

- **SIX SIGMA**

BRUE, G. 2002. *Six Sigma for managers*. York: McCraw-Hill. 189p. ISBN 0-07-138755-2.

CHOWDHURY, S. 2001. *You can get to the power of Six Sigma*. USA: Dearborn Trade. 128p.

## Appendices

### *Annexure 1: Value stream map data for Final Assembly*

Activity	Value adding duration	Non-value adding duration
<b><u>Install landing gear handle</u></b>		
Trim side channel lip	00:20	
Position the rod to mark the front attachment point	00:40	
Drill the hole	00:30	
Temporary install seat to check position	00:37	
Adjust Landing gear push rod 2 backwards	00:09	
Remove star washer	00:12	
Tighten bolt of driver	00:07	
Fetch a bolt (flat head) and modify it		00:16
Modify landing gear plate	00:43	
Drill holes in side channel	00:20	
Install plate	00:11	
<b><u>Install high pressure pipe with elbow</u></b>		
Tighten bolt from main cylinder to pipe	00:06	
<b><u>Install reservoir</u></b>		
Measure position of holes	00:07	
Install bolts/bracket	00:13	
<b><u>Install nose hook mechanism</u></b>		
Repair rudder pedal assembly		00:14
<b><u>Functional test of landing gear</u></b>		
Organize tools		00:16
<b><u>fasten flap plate</u></b>		
Grind away lip of fuselage at landing gear area	00:05	
<b><u>Install side air vent</u></b>		
Clean of all excess spa bond	00:06	
Production Manager test water system lever		00:07
<b><u>Installing Rudder pedals</u></b>		
Checking modified assembly	00:40	
Feeding rudder cable into rudder cable housing	00:07	
Crimp sleeve to rear end of rudder cable	00:12	
Drill hole in rudder pedal adjustment handle	00:05	
Drill hole in handle	00:39	
<b><u>Rudder install</u></b>		
Prep rudder area - clean off all floc on fin false spar	00:10	
Clean rudder hinge area with compressed air and acetone	00:06	

Activity	Value adding duration	Non-value adding duration
<b>Sand &amp; seal cockpit floor</b>		
Re-plan		00:15
Re-plan		00:13
Sanding cockpit floor with sanding paper	00:10	
Sanding with sanding paper	00:09	
Blow out dust out of cockpit	00:06	
Seal cockpit floor with sanding sealer	00:09	
<b>Trim system</b>		
Production Manager repairs trim assembly		00:16
Assemble trim system	00:06	
Removing spring		00:13
Filling hole	00:06	
Problem - too much resistance at back of stick		00:24
<b>fit tailplane</b>		
Measure ranges of tailplane	00:06	
Check operation - elevator system too stiff	00:17	
<b>Install foot rubber</b>		
Cut rubber using template	00:10	
Men's room		00:12
<b>Install canopy</b>		
Install canopy	00:07	
Canopy jams when closing		00:08
Removing built-up on canopy pins		00:12
Canopy jams when closing		00:14
Removing binnacle		00:49
Reinstall binnacle		00:19
Fetch contact adhesive from Fuselage Pre-Close		00:07
Grind away bootring preventing stick to get full aileron range	00:10	
<b>Prep centre section table for bonding</b>		
Arrange to turn fuselage around		00:05
Fetch fest tool		00:04
Turn fuselage around		00:05
Vacuum below centre table		00:05
Looking for foreign objects below centre section table	00:08	
<b>Fit canopy</b>		
Removing masking	00:18	
Installing binacle	00:08	
Tighten struts	00:11	
Install canopy and check clearance, adjusting struts	01:12	
Check canopy fit	00:07	
Locking struts	00:09	

Activity	Value adding duration	Non-value adding duration
<b><u>Lock wheelbrake</u></b>		
Check kits		00:08
Tighten wheel lock	00:15	
Continue	00:05	
Tighten wheel brake lock	00:10	
<b><u>Fit canopy</u></b>		
Sand on blue marks	00:14	
Check gaps	00:29	
<b><u>Inspection of centre section</u></b>		
Inspection of centre section	00:07	
Inspection of centre section	00:21	
Fetch paper work - final inspection		00:06
Checking drawings		00:16
<b><u>Install landing gear spring</u></b>		
Landing gear spring	00:49	
<b><u>Install wheel doors</u></b>		
Remove rivets from fuselage with screw driver	00:08	
Coutersink holes	00:05	
Clean holes in fuselage	00:05	
Masking area to cast stopper	13:02	05:04

## ***Annexure 2: Six Sigma tools and techniques***

- ***Project charter***

The Six Sigma project charter is a document that states the details of the improvement, opportunity to the management of the company and the Six Sigma team. It is a living document that can be revised during the life of the project (Carpenter Group LLC, 2011).

The project charter normally consists of the following sections:

- The business case;
- The problem statement;
- The goal statement;
- The scope statement;
- Cost of poor quality;
- Required resources; and
- Key performance metrics

- ***Suppliers-Inputs-Process-Outputs-customer diagram (SIPOC)***

A SIPOC diagram is a high-level map of the process (P) that shows the basic steps of the process. It indicates who the suppliers (S) are that provide (I) to the process. The process adds value that results in output (O) that the customers (C) require. BasicKnowledgeSource (2011) defines the different elements of the SIPOC diagram as follows:

- **Suppliers** – Internal or external suppliers to the process that is being investigated.
- **Inputs** - Inputs that are required for the process to function (for example materials, forms, information, staff, etc.)
- **Process** - The process is defined by one block that represents the entire process.
- **Outputs** - Outputs to the internal or external customers. Anything that the business unit distributes (for example reports, ratings, products, documents, etc.)

**Customers:** Internal or external customers to the process. This includes everyone who receives outputs delivered by the process (for example managers, CEOs, boards of directors or other departments).

Figure 0-1 shows an example of a SIPOC diagram.

Suppliers	Inputs	Process	Outputs	Customers
List the suppliers of any inputs to this process (materials, resources, services or information).	List the inputs to this process (materials, resources, services or information).	Describe the process and/or list the key process steps.	List the outputs of this process (products, services or information).	Identify the customers of these process outputs.
Marketing	Interview notes	<pre> graph TD     Start([Start]) --&gt; Define[Define market]     Define --&gt; Plan[Plan VOC investigation]     Plan --&gt; Collect[Collect VOC data]     Collect --&gt; Analyze[Analyze VOC data]     Analyze --&gt; Summarize[Summarize customer needs]     Summarize --&gt; End([End])                     </pre>	Customer needs summary	Product Team
Product Team members	Surveys		Customer needs data dictionary	
Technical Support	Published market data		Product definition	
Customer Service	Focus group reports		Sales forecast	
Field Service	Video observation			
Customers				
Market research firms				

Figure 0-1: Example of a SIPOC diagram (Elite Consulting)

- **Stakeholder analysis**

A stakeholder analysis is conducted with a view to identify the stakeholders of a project and to assess them. It is important to know who can influence the project positively and negatively. This will help towards planning a strategy to win them over (Elite Consulting). Figure 0-2 shows a stakeholder chart for organising the stakeholders in terms of their power (influence) and their interest in the project.



**Figure 0-2: Stakeholder chart**  
(Elite Consulting)

- ***VOC analysis***

The customers' needs for development projects must be analysed. According to Kenneth Crow (2011), the VOC analysis should include the following:

- How to identify target customers;
- Which customers to contact in order to capture their needs;
- What mechanisms to use to collect their needs; and
- A schedule and estimate of resources to capture the voice of the customer

- ***Affinity diagram***

Customer needs that are gathered must to be organised. The affinity diagram is a useful tool assisting with this. The process is explained as follows (Kenneth Crow, 2011):

1. Brief statements that explain the customer needs are written on cards;
2. To avoid any misinterpretation, a data dictionary is prepared;
3. The cards are organised into logical groupings or related needs, making it easier to identify any similar needs; and
4. These cards serve as a basis for organising the customer needs.

- **Critical-to-Quality (CTQ) tree**

The Critical-to-Quality tree is used to determine what needs to be measured in order to drive the improvements in the eyes of the customer. Therefore, the CTQ tree provides a graphic representation which ties the progression of the requirements together. The progression starts with the want or needs of the customer, which leads to the drivers within the process that must be controlled. This, in turn, leads to the critical-to-quality characteristics that need to be measured in order to control the drivers (Educate virtually, 2011). Figure 0-3 shows an example of a CTQ tree that indicates the needs, drivers and the CTQs.

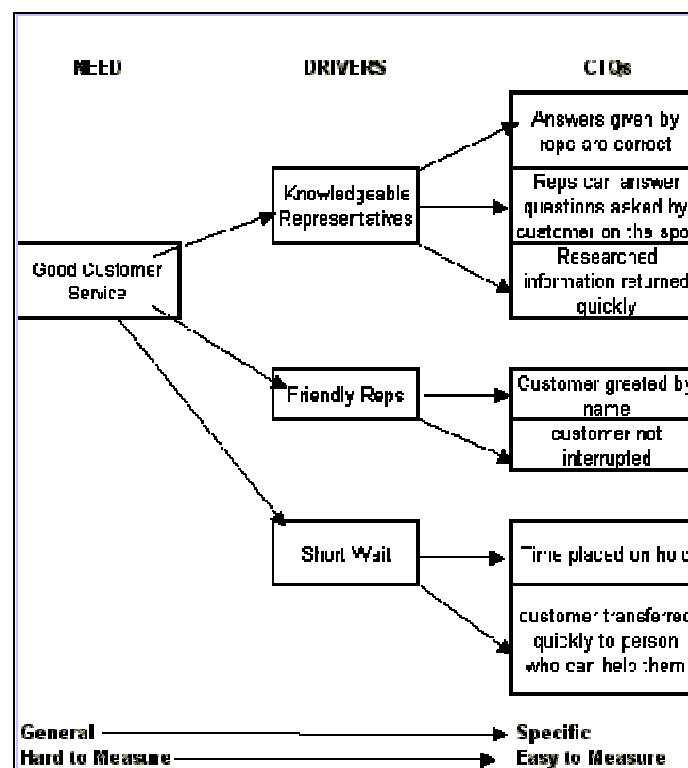


Figure 0-3: Example of a CTQ tree  
(Educate virtually, 2011)

- **Prioritisation matrix**

Good time management is the art of doing the right thing at the right time. This will result in producing the greatest value for oneself and the organisation, per hour (Farmers, 2011). In order to achieve this, one must be able to evaluate and prioritise tasks.

A prioritisation matrix utilizes two criteria to prioritise tasks:

1. **Benefit of the task** – The degree towards the activity move the project towards the objectives; and
2. **Effort required of the task** – The amount of effort required between the present moment and the time by which the task will be completed.

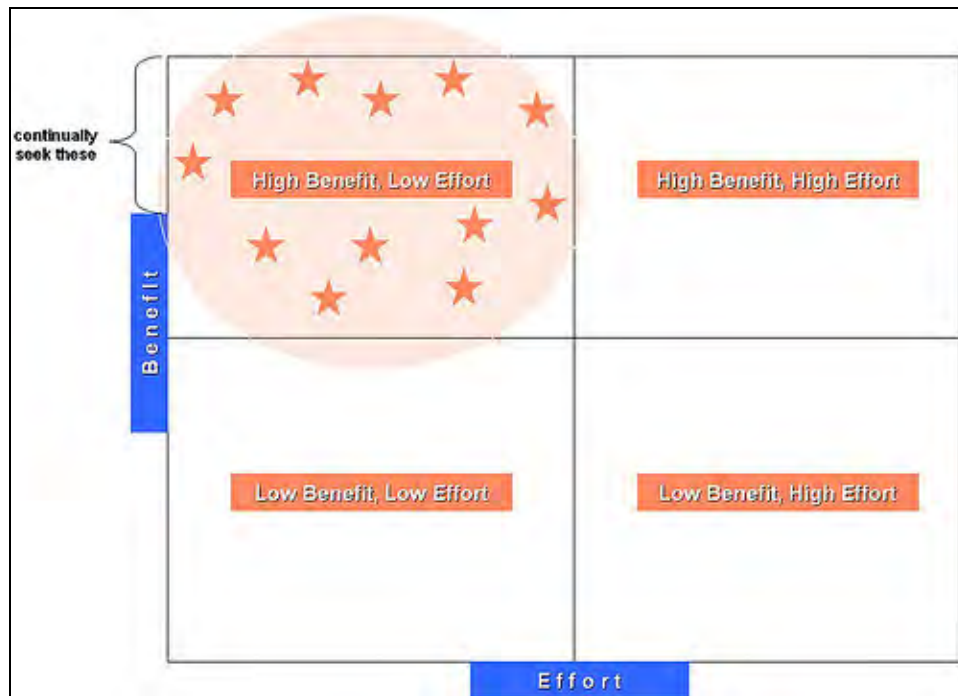


Figure 0-4: Prioritisation matrix example

The simple matrix in Figure 0-4 assists a team in focussing their energies on the activities by which a project will benefit the most.

- ***Gage repeatability and responsibility study***

Gage Repeatability and Reproducibility refers to the amount of measurement variation introduced by a measurement system, which consists of the measuring instrument itself and the individual using the instrument. The Gage R & R study quantifies the following:

1. Repeatability – Variation from the measurement instrument;
2. Reproducibility – Variation from the individuals using the instrument; and
3. Overall Gage R&R, which is the combined effect of (1) and (2)

The overall Gage R&R is usually expressed as a percentage of the tolerance of the CTQ criteria. A value of 20% or less is usually considered acceptable (DMAIC tools, 2011).

- **Control charts**

Control charts are used to monitor the output of a process. The charts have an upper limit and a lower limit. Any point that is plotted outside these limits is considered to be a 'special cause'. The control chart gives timely warnings of these 'special causes' (see Figure 0-5). Additionally control charts monitor the process mean, the process variation or a combination of both (MIC quality, 2011).

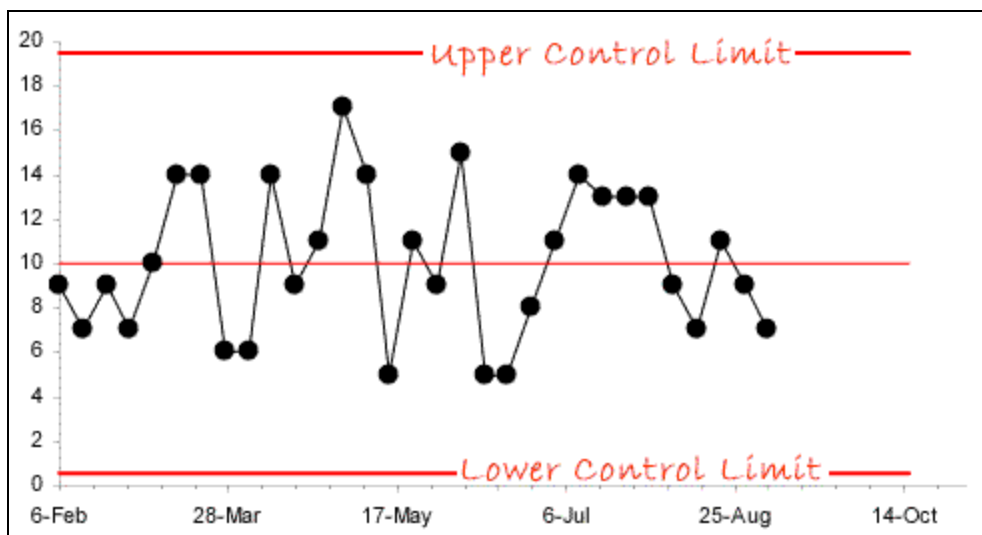


Figure 0-5: Control chart example  
(MIC Quality)

- **Run charts**

According to MIC Quality (2011) a run chart is a chart that plots values in a time order (see Figure 0-6). A run is defined as one or more consecutive points on the same side of the median (centre line). The runs are analysed in order to indicate 'special cause' in on of the following scenarios:

- The presence of too few, or too many, runs for the number of points;
- Too many data points in a run;
- An unusually long sequence of ascending or descending data points; and
- Too many points forming a zigzag pattern

Run charts are similar to control charts, however the important differences are:

- Control charts are more applicable for monitoring ongoing processes; and
- Run charts are more appropriate for investigating short term process improvement opportunities.

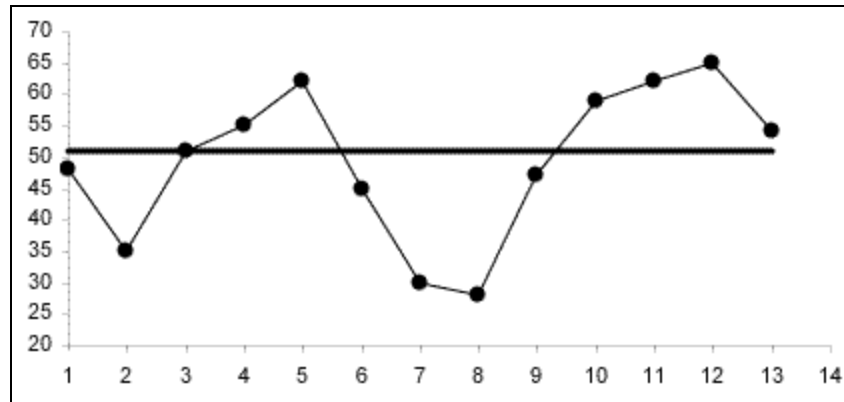


Figure 0-6: Run chart example

- **Histograms**

“A histogram is a graphical method that represents the distribution of values in a data set. The data values are grouped into ranges and shown as bars” (MIC Quality, 2011).

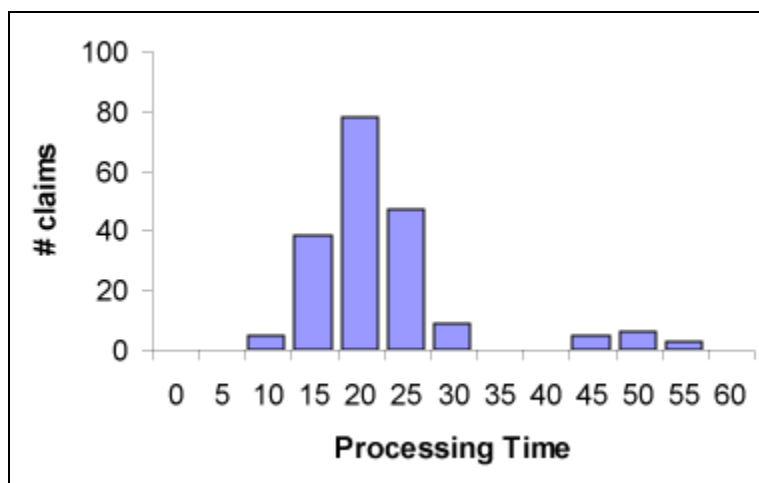


Figure 0-7: Example of a histogram  
(MIC Quality)

- **Pareto charts**

Pareto charts are used to analysis the frequency of occurrences diagrammatically, in order to identify and display the results generated by a specific cause (see Figure 0-8). This analysis is frequently used to decide where to apply initial efforts in order to have the maximum effect (Elite Consulting, 2011).

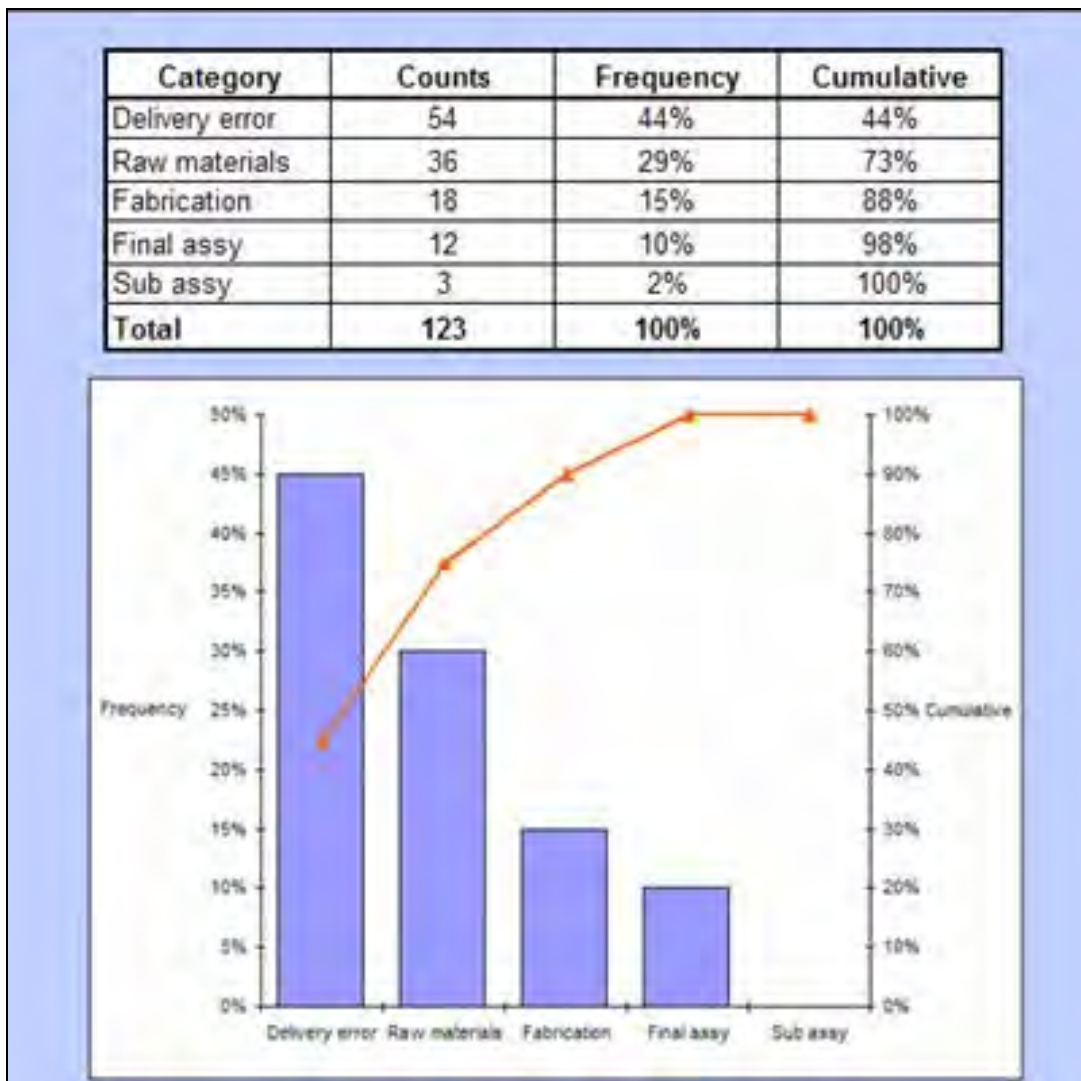


Figure 0-8: Pareto chart example

- **Cause-and-defect diagram (fishbone / Ishikawa diagram)**

According to Elite Consulting (2011), a cause-and-effect-diagram illustrated the main causes and sub-causes that supposedly led to the problem that is studied (see Figure 0-9).

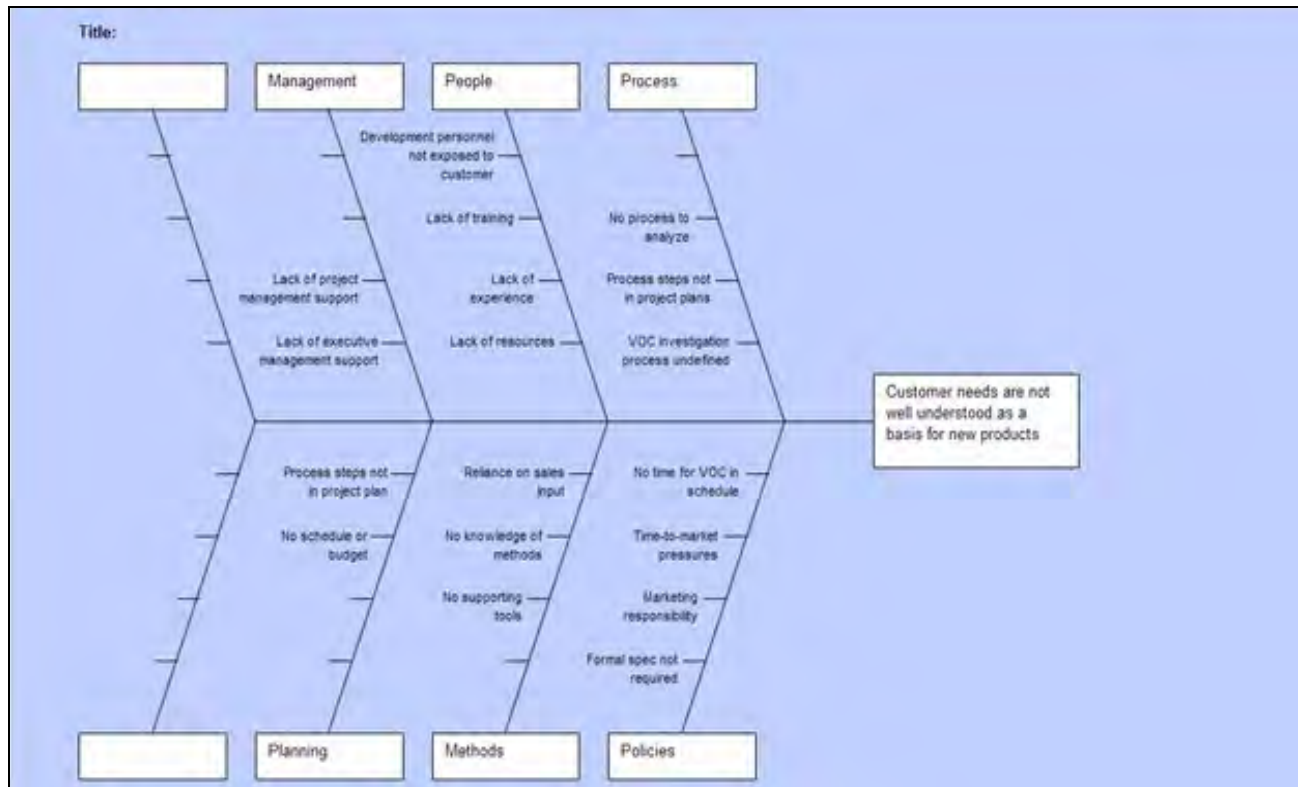


Figure 0-9: Cause-and-effect diagram (fishbone diagram)  
Elite Consulting (2011)

- **Regression analysis**

“Regression analysis involves finding the line of best fit through a series of points” (MIC Quality, 2011).

- **Scatter plots**

“Scatter plots are used to show the relationship between two variables” (MIC Quality, 2011). See Figure 0-10.

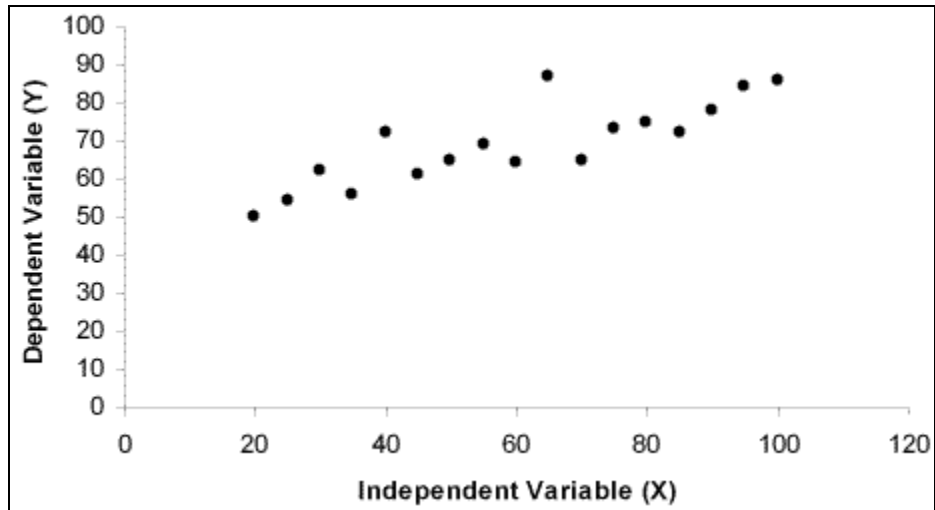


Figure 0-10: Example of a scatter plot

- ***Design of experiments (DOE)***

“Experimental design involves conducting a systematic series of tests in order to discover the relationship between the factors that affect a process and the response” (MIC Quality, 2011)

- ***Failure mode and effects analysis (FMEA)***

Failure mode & effects analysis (FMEA) is a method used to evaluate risk. Each potential failure mode is evaluated according to the following criteria:

- S - Severity of the consequences if it should occur;
- O - Probability of occurrence; and
- D - Probability of detection before delivering.

Each one of the above-mentioned factors is rated on a scale from 1 to 10. These three values are then multiplied with each other in order to find the Risk Priority Number (RPN). Should the RPN be above a specified limit, action will have to be taken to reduce it (MIC Quality, 2011).