



THE DEFENCE INDUSTRY HAS TO MANAGE ENGINEERING PROCESSES IN A DIFFERENT MANNER TO GET PRODUCTS TO THE MARKET FASTER

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ABSTRACT

The defence industry in South Africa has to compete against very strong competition in the global world. Development time of products has to be shorter, because customers demand a very quick response.

This study can be summarized in this question: *“How can processes be improved to comply with the requirements of the customer in terms of schedule and quality?”*

A combined process improvement method is defined by using a combination of Theory of Constraints (TOC) and Six Sigma. TOC focuses the improvement process on the constraint(s) within the process, whereas Six Sigma focuses on the inherent variation(s) within the processes in a system.

1. INTRODUCTION

Denel Aerospace Systems is a division of Denel, the South African armaments production company. Formerly known as Kentron, it underwent the name change in April 2004. Aerospace Systems specializes in the development, production, integration and support of Guided Weapon Systems, Unmanned Aerial Vehicle Systems, Attack Helicopters and Air Defence Systems. Aerospace Systems delivers these solutions with a long-term commitment to providing customer support and system upgrades. (Botha, [1])

Denel Aerospace Systems and other local defence industries compete in the global marketplace. This has placed great pressure on the local defence industry to get high-quality products to the market faster, at very competitive prices. To be competitive in the global marketplace, products must be on time, within budget and of outstanding quality. The most important factor is that the product must meet the requirements of the customer. The processes as used within the company need continuous improvement. This will ensure that the company remains competitive in today's marketplace.

There is a variety of process improvement methods that are used within the defence and commercial industry. The following process improvement methods have been analysed in this study: Concurrent Engineering, Just-In-Time, Theory of Constraints, Six Sigma, System Engineering, Outsourcing and Business Process Reengineering.

The objectives of this study are to define a method for continuous process improvement in order to:

- meet the requirements of the customer with regard to specifications, price, schedule and quality;
- improve the rate at which the production process generates money through sales;
- increase the cash flow and net profit of the company.

The following research strategy has been followed in this study to meet the objectives:

- Examine the current production process as used within Denel Aerospace Systems.
- Formulate a process improvement theory.
- Recommend the application of the process improvement theory.

2. THEORETICAL FRAMEWORK

Organizations have to use process improvement methodologies to enhance the competitiveness of the organization. The chosen process improvement method has to have the following characteristics:

- Adaptive to rapid changes regarding volumes and delivery dates.
- Close relationship with customer - the customer must be involved in the production process from early on, must know where the delays are, as well as the reasons for the delays or defects.
- Measurements must be visible to all management - delays in process, number of defects, net profit, manufacturing progress, solutions for defects or problems.
- Teams must be identified to plan, implement, analyze and control the process improvement methodology. The teams have to focus on the input, process and output of the production process as a system. The team must also ensure that there is feedback between the three stages of the production process.
- Improvements must be incremental to verify the effect of change on the environment (facilities, finances, material (inventory), resources, documentation).

2.1 TOC

TOC is a system approach, based on the assumption that every organization has at least one factor that inhibits the organization's ability to meet its objectives. The normal objective of a business is to maximize profit. TOC emphasizes the maximization of profit by ensuring that the factor that limits production is used more efficiently.

In TOC, an analogy is often drawn between a linked sequence of processes and a chain. If you want to improve the strength of the chain, concentrate your efforts on strengthening the weakest link. To do this, first identify the weakest link, which is the constraint. Then concentrate on improving the weakest link without subjecting the organization to too great a load. Eventually, the weakest link will improve to the point where it is no longer the weakest link, thus eliminating the constraint and maximizing throughput. The process will then be repeated by identifying the next weakest link.

“TOC is a management philosophy developed by Dr Eliyahu M Goldratt that can be viewed as three separate but interrelated areas - logistics, performance measurement, and logical thinking. Logistics includes drum-buffer-ropo scheduling, buffer management and VAT analysis. Performance measurement includes throughput, inventory and operating expense, and the five focusing steps. Thinking process tools are important in identifying the root problem (current reality tree), identifying and expanding win-win solutions (evaporating cloud and future reality tree), and developing implementation plans (prerequisite tree and transition tree)” (Cox, James F,[2])

TOC introduces the concept of “Throughput Accounting” which is structured using the following three concepts; Throughput, Inventory, and Operating Expenses:

- Throughput (T): The amount of money a company generates through sales, and not production, that is, Revenue minus real variable costs.
- Inventory (I): Those items purchased for resale and include finished goods, work-in-process and raw materials. Inventory is always valued at purchase price and includes no value-added costs.
- Operating Expense (OE): The quantity of money spent by the firm to convert inventory into sales in a specified time period. Direct labour sales are included in OE, as it is a fixed amount that does not vary as volume varies.

In TOC implementation, it is intended to continuously repeat the Five-Step Focusing Process and by doing so continuously increase throughput:

- Step 1: Identify the System Constraint
- Step 2: Decide how to exploit the System Constraint
- Step 3: Subordinate All Else to the Constraint of the System
- Step 4: Elevate the Constraint of the System
- Step 5: If in Step 4 the Constraint is broken, Go to Step 1

TOC has three ways to improve business performance, namely:

- Increase T
- Decrease I
- Decrease OE

There are six basic tools that make up the thinking processes. Each can be used independently or in various combinations depending on the need at the time.

- Current Reality Tree (root cause analysis)
- Evaporating Cloud (conflict resolution)
- Future Reality Tree (solution testing)

- Negative Branch (negative side-effect abatement)
- Prerequisite Tree (reaching an ambitious target)
- Transition Tree (fail-safe action planning)

2.2 Six Sigma

Six Sigma incorporates the basic principles and techniques used in business, statistics, and engineering. These three form the core elements of Six Sigma, which improves the process performance, decreases variation and maintains consistent quality of the process output. This leads to reduction in defects and improvement in profits, product quality and customer satisfaction.

“Six Sigma: A comprehensive and flexible system for achieving, sustaining and maximizing business success. Six Sigma is uniquely driven by a close understanding of customer needs, disciplined use of facts, data, and statistical analysis and diligent attention to managing, improving, and reinventing business processes.” (Pande Peter S,[3])

The phrase “Six Sigma” derives from statistics. Sigma is a Greek symbol which denotes standard deviation, in other words - variation - around the mean value, typically on a bell curve. Processes have upper and lower acceptable limits. Anything outside these limits is considered a defect, or unacceptable outcome. Six Sigma is about defining the best measures of a process, implementing those measures, tracking them, and making adjustments so that more of the outcomes fall within the acceptable range (reducing the number of defects).

An example of the difference that Six Sigma can make is one typo per page (3-sigma level) versus one typo for an entire small library (6-sigma level).

Six Sigma uses a five-phase improvement cycle: Define, Measure, Analyze, Improve, and Control - or DMAIC.

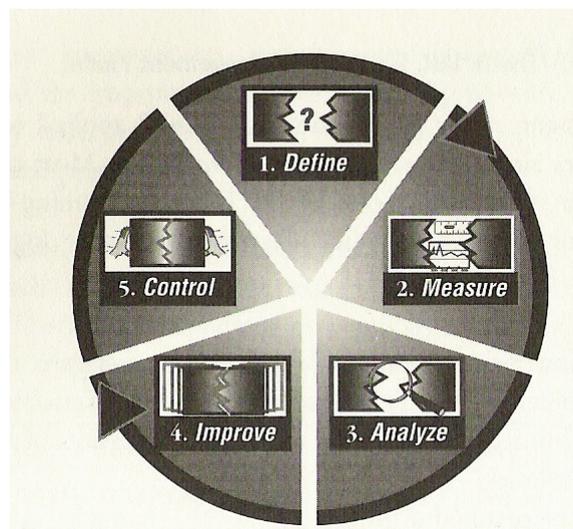


Figure 1: Six Sigma improvement model (Pande S, [3])

2.3 Formulation of Combined Theory

TOC focuses on the constraint within a process and uses the TOC improvement process to submit the whole process to the capacity of the constraint. All efforts will be used to increase the capacity of the constraint, since the constraint determines the throughput of the process. Six Sigma analyses and measures the sigma level of the process. The sigma level indicates the effectiveness of the process. The data as measured on the process will be analyzed and show where the weak points are within a process. Incremental changes will be introduced in the process in order to run it at maximum capacity.

Use the TOC method to focus on the constraint within the process, as the throughput of the process is determined by the constraint. Running non-constraints at their maximum capacity will not maximize the throughput of the process. Use the Six Sigma methodology to improve the efficiency of the constraint up to its maximum capacity.

The combined methodology consists of the following steps:

Step 1. Use TOC to identify the constraint within the current process

The sources of constraints within the process can be defined as:

- External Sources

The external sources fall into three categories:

- a) Voice of the customer
- b) Voice of the market
- c) Comparison with competitors

These sources identify opportunities to better meet customer requirements, respond to trends in the market, or counter competitor strategies and capabilities.

- Internal/ External sources

This will help to identify challenges that the organization faces in defining and/or achieving its market and customer strategies. The following questions can be asked to define these sources:

- a) What are the barriers between us and our strategic goals?
- b) What new acquisitions have to be integrated so that they are profitable and aligned with our desired market image?
- c) What new products, services, locations or other capabilities do we hope to launch, to better provide value to customers and shareholders?

- Internal sources

The internal sources are the “Voice of the process” and the “Voice of the employee”. The goal is to pay closer attention to various people’s perspective on ways in which processes can be improved to the benefit of the business, customers, shareholders and employees. The following questions can be asked to define the sources:

- a) What major delays slow down our processes?
- b) Where is there a high volume of defects?
- c) What concerns or ideas have employees or managers raised?

Make use of Six Sigma to Define, Measure and Analyze the requirements of the customer in terms of the products and services. When this has been done, the constraints within the current process can easily be identified. The Six Sigma Define, Measure and Analyze steps will define the ideal process. This can then be compared to the current process.

Step 2. Determine a strategy to exploit that constraint to its fullest capability

In order to exploit the constraint to its fullest capability, accurate measurements must be taken on the constraint. Measure the defective rate and process Sigma for the constraint in a process. These values are an important management tool that will indicate the effectiveness of the constraint within a process, which will determine the throughput of the process. No delivery delays can be allowed to the constraint, which has to be operated at Six Sigma, 99,9997% perfect. Reduce the set-up times on the constraint to zero. Apply Six Sigma quality control procedures to eliminate defects from entering and leaving the constraint. Adopt preventive maintenance practices for the constraint.

Step 3. Subordinate everything else to the decision made in step 2

The downstream processes must be monitored closely to eliminate waste. Once the constraint has been used to create something, one does not want to lose it to some blunder downstream. The upstream processes must meet the demands of the constraint, and waste must be eliminated. The defect rate and process Sigma values of the upstream and downstream processes have to be calculated. These values must be managed to keep them at an acceptable level. Defects after the constraint process have to be kept to a minimum. With these calculated values, the defects can be managed to a minimum. Without these calculations, effective management will not be possible.

Step 4. Elevate the system's constraint(s)

Analyze the measured data by using the root cause hypothesis/analysis cycle. Identify the gaps between current performance and goal performance.

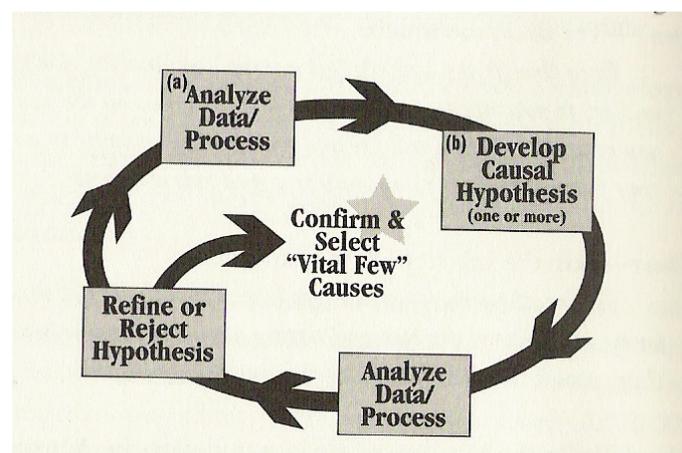


Figure 2: Root cause hypothesis/analysis cycle (Pande S, [3])

There are two key sources of input to determine the true cause of the targeted constraint:

- **Data Analysis:** use measures and data to discern patterns, tendencies, or other factors about the constraint that either suggest or prove/disprove possible causes.
- **Process Analysis:** deeper investigation into, and understanding of, how work is being done to identify inconsistencies or problem areas that might cause or contribute to the constraint.



Do not get caught in these pitfalls:

- Shortcutting the cycle prematurely, declaring the suspected cause “guilty” and moving to solutions without sufficient evidence.
- Getting stuck in the cycle, never being convinced that you have sufficient data.

Now is the time to take action. To launch the improvements on the constraint successfully, focus on the “four P’s”: Planning, Piloting, and Problem Prevention:

- **Planning:** Changing a process demands strong project management skills. An implementation plan that covers actions and resources must be defined. Communication is important, as it becomes crucial when the complexity of the solution increases.
- **Piloting:** Make small changes at a time. The chances of unforeseen problems are high, and the learning curve can be steep when changing to a new way of doing things.
- **Problem Prevention:** Ask “What If” questions to ensure that every solution to the problem has been investigated.

Step 5. If the constraint is broken, return to step 1

The process will have to be reapplied, perhaps many times. It is important not to let inertia become a constraint. Do not allow rules, policies and procedures to become the constraint. Review and change the rules, policies and procedures that initially caused the constraint. The measurements on the process must be visible to all management levels.

Use the Six Sigma method to **control** the improvement process by the development, documentation and implementation of an ongoing monitoring plan. Everyone related to the process has to be trained in the process improvement methodology. The continuous improvement of processes must become part of the organization’s culture.

2.4 Benefits of the Combined Theory

The combined methodology not only focuses on improvement of the constraint, the upstream and downstream processes are also addressed to ensure that the constraint does not waste time on defects, and that the output of the constraint does not get defected by downstream processes. TOC concentrates only on the constraint.

The combined methodology uses TOC to focus the analysis on the constraint process in order to ensure that the correct problem in the system is addressed. In low-volume production runs, it is important to identify the problem within a process quickly and efficiently. For example, in a production run of ten products, a single defect will cause the defect rate of process to be 10% and the Process Sigma value to be 2,78. This value indicates that 90% of products are within acceptable limits.

The voice of the customer is also used to determine the constraints in the system. The importance of the customer’s requirements is highlighted.

3. RESEARCH METHODOLOGY

The production process as used at Denel Aerospace Systems, has been used in this study as an example to analyze the potential improvement of the production process by means of the application of the combined methodology. The following process has been followed:

- The current process as used has been analyzed and documented.
- Measurements have been identified in the current production process. The current measurements have been verified and potential new measurements have been identified.



- The measurements have been done on the current production process to establish the constraints within the system.
- The measured data have been analyzed.
- Improvements have been identified in the system, based on the analyzed data.

The following measurements are currently done in the production process:

- **Defect reports** are generated for each failure during incoming inspection. The defect reports are logged on the MRP system.
- **Failure Reporting, Analysis, Corrective and Preventive Actions (FRACAs)** are generated for each failure during the manufacture and testing of the product. The FRACAs are kept on an internal database and are not linked to the Material Resource Planning (MRP) system. It is the responsibility of the assigned production engineer to manage the completion of the FRACA and the Engineering Change Proposal (ECP) that might flow from the FRACA.

The following additional measurements will be added to this research:

- **Adjustment rate of schedule:**
Measure the total number of approved Master Product Schedules (MPSs) and the total quantity of adjustments on the MPS.
- **Rate of late internal orders:**
Measure the total number of internal orders and of late deliveries on internal orders.
- **Rate of late external orders:**
Measure the total number of external orders and of late deliveries on external orders.
- **Incoming inspection defect rate:**
Measure the total number of inspections and of defects found during the inspections.
- **Assembly failure rate:**
Measure the total number of assemblies done and of the failures that occurred during the assembly process.
- **Acceptance testing failure rate:**
Measure the total number of assemblies that have been tested and the total number of failures that occurred during testing of the assembly.
- **Final inspection failure rate:**
Measure the total number of assemblies that have been inspected and the total number of assemblies with failures during the final inspection.
- Note the processing time in days, from receiving the customer order up to the approved MPS.
- Note the processing time in days, from the approved MPS up to when internal/external orders are placed.
- Note the processing time in days, from when goods are received up to when goods are booked into store.
- Note the processing time in days for the release of production kits for manufacture.
- Note the processing time in days of the manufacturing process, which includes assembly, testing and inspection.
- Note the processing time in days for setting up the product release documentation - which includes Build History Documents (BHDs) and Inspection Release Certificates (IRCs).
- Note the processing time in days for the product dispatch activities, which include packing and delivery documentation.

The calculation of the rates will be done as follows:

- **Defective Rate** = Total defects / Total Opportunities
- **Quality level** = 1 - Defective Rate. The quality level corresponds to the area under the normal curve that represents the part of the process that is non-defective. A normal

deviate (z-score) for the quality level can be calculated by using the Excel® NORMSINV() function of the quality level.

- **Process Sigma** = Z-score + 1,5 sigma shift (Sauro J, Article [1])

4. RESULTS

The defect rate and process Sigma have been calculated for the following:

- Mechanical part inspection
- Electronic components inspection
- PCBs and labels
- FRACA

The results as obtained for the mechanical parts inspection are shown in the example below.

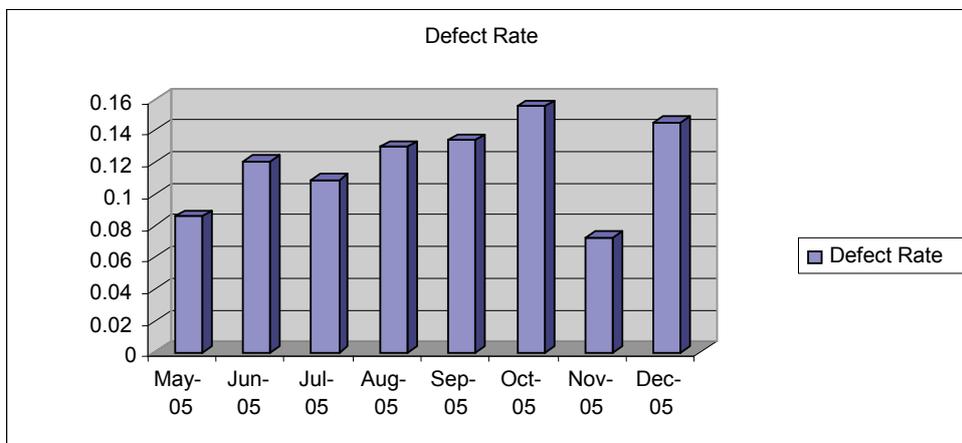


Figure 3: Mechanical parts defect rate

The average defect rate for mechanical manufactured parts is 11,85%. The total number of inspected mechanical parts was 4 591, and with an average defect rate of 11,85%, 544 defective parts were found in eight months.

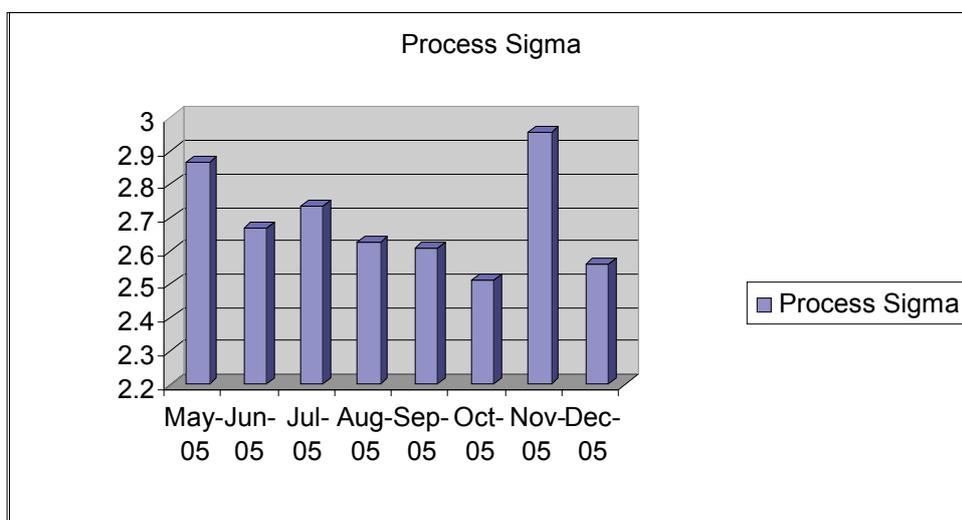


Figure 4: Mechanical parts Sigma value

The average process Sigma value for manufactured mechanical parts is 2,68. The Sigma value indicates the number of products that were produced by the mechanical manufacturing process within acceptable limits. During this sample, 88,15% of products were within acceptable limits. The ideal situation is 99,9997% of products within acceptable limits.

Mechanical component inspection

Mechanical	Defects	Total	Defect Rate	Qual Level	Z-score	Process Sigma
May-05	52	605	0,08595041	0,91405	1,366121884	2,866121884
Jun-05	63	522	0,12068966	0,87931	1,171546456	2,671546456
Jul-05	62	569	0,10896309	0,891037	1,232061646	2,732061646
Aug-05	100	771	0,12970169	0,870298	1,127802645	2,627802645
Sep-05	92	687	0,13391557	0,866084	1,108071208	2,608071208
Oct-05	103	663	0,15535445	0,844646	1,013735716	2,513735716
Nov-05	40	553	0,07233273	0,927667	1,458635767	2,958635767
Dec-05	32	221	0,14479638	0,855204	1,059015535	2,559015535
	544	4591	0,1184927	0,881507	1,182555675	2,682555675

Table 1: Mechanical parts inspection results

Only the incoming inspection results are currently available on the material management system. The measurements are not categorized according to project, which makes it difficult to make a decision on the defects as shown on the material management system. Additional calculations such as the defect rate and Process Sigma value have to be available to all management levels at all times. Due to the low volumes of production at Denel Aerospace Systems, it will be difficult to observe any trends in the results. Defects therefore have to be managed to keep them to a minimum - strive towards zero defects - Six Sigma.

5. INTERPRETATION OF RESULTS

The results show that the inspection procedure, as used in the production process, needs improvement. The measurements as identified in this study have to be visible to all levels of management.

The processes used for the manufactured mechanical parts must be inspected and qualified at the manufacturer. This will reduce the number of defective parts received. When the parts are inspected at the manufacturer, no time will be wasted during the production process to check the quality of incoming products. The products can then be delivered directly to the production process. This will reduce the set-up time of the production process.

Due to limited time and the restructuring of the organization, it was not possible to implement the combined methodology in the production process. In this study, only recommendations have been given on how to improve the current production process.

6. CONCLUSIONS AND RECOMMENDATIONS

TOC and Six Sigma have been used with great success in the manufacturing industry. The effectiveness of the combined theory still has to be verified. It can be seen from the

results that measurements are of great importance in the production process. Measurements will assist management to make more calculated decisions.

In the study, a survey has shown that the quality of delivered mechanical parts causes major problems on the production line. It causes unnecessary delays because defective parts have been assembled into assemblies. The delivery of defective parts to the production line has been identified as a constraint in the production process. The constraint has to be exploited. Appoint inspectors at the external suppliers of mechanical parts. These inspectors must train the personnel of the external supplier to deliver products that adhere to the specifications of the parts. Calculate the defect rate and process Sigma of each manufactured part. Use these values to rate the external suppliers. A proposed criterion could be to manufacture high-precision mechanical parts at an external supplier with a process Sigma higher than 4, which indicates that 99,37% of parts are within acceptable limits. Manufacture parts that are not critical at an external supplier with a process Sigma of between 2,78 and 4. A process Sigma of 2,78 indicates that 90% of parts are within acceptable limits. When this external inspection is in place at the external suppliers, the parts can be delivered directly to the production line. This delivery will reduce any further delays due to incoming inspection. All delays must be kept to a minimum, as time lost during unnecessary delays cannot be recouped.

In order to launch the improvements into the production process, the following actions have to be carried out:

- (1) Plan all the actions needed to improve the delivery of quality products.
- (2) Make small changes at a time and measure the effect of the change on the system.
- (3) Ask 'what if' questions to prevent new problems from occurring.

When the delivery of defective parts to the production line has been solved, repeat the combined process to identify other constraints in the system.

Process improvement must become a lifestyle for optimum effectiveness. The status quo of a process must not be accepted as the norm. The old way of doing things must be challenged. The measurements as defined for a process are very important, as is the value of people during process improvement. The attitude of the people can make or break a process improvement process. The people involved in the process must understand their value in the process. By knowing their value, they will add more value to the process.

Process improvement involves continuous change. The defence industry is used to fixed processes such as the military standards that have been used for many years. The defence industry must be more flexible towards change; this will give them a competitive edge. Continuous process improvement will ensure that engineering processes are optimal.

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