**Six Sigma Black Belt Competencies**

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| Lean and Six Sigma Black Belt Competencies (BS ISO 18404:2015) | | | | | |
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| Index | 1 | Table | A.2 | Original index | 1 |
| Competency | | Organisational benefits identification and prioritisation. | | | |
| Performance criteria | | Identification of the importance of using quantified organisational benefits or goals to guide project selection. Selection and use of an approach. | | | |
| Understanding the competency | | Describes the appropriate identification of the organisations opportunities, the benefits of removing concerns and the relationship to and organisation’s business goals and how project / problem selection relates to these goals. Describes appropriate prioritisation approaches and techniques and their use. | | | |
| Applying the competency | | Demonstration that the selection of each project is in agreement with these goals and objectives. Demonstration of correct selection and use of prioritisation, matrices, multi-voting techniques, strategy grids. | | | |
| Managing the competency | | Evidence of review of Green Belt project benefits and linkages to organisational goals as appropriate. | | | |
| Training the competency | | Not applicable. | | | |
| Competence statement | | | | | |
| I have experience selecting projects not only for Six Sigma but in general as a head of a research group. I understand the importance of project selection for the successful completion of projects. I based my decision on various factors such as Voice of Customer (VoC), organisational strategy, profitability and customer / employee satisfaction. | | | | | |
| Associated evidence | | | | | |
| I am familiar with different prioritisation tools that help project selection: Pareto Priority Index, Prioritisation Matrix, Difficulty-Profit chart, Benefit / Cost Ratio, Discounted Cash Flow, Internal Rate of Return, Scoring model, etc.  An example of project selection is when I selected a project based on a full analytical criteria method of prioritisation matrices. The project consisted on developing a low cost fixture for trimming carbon fibre. An initial meeting with the customer provided me with the criteria for such a fixture. The customer wanted a low cost, fast turnaround, high tolerance fixture. They were not very interested in durability as it was going to be used only for a small batch. After understanding the customer requirements and how the requirement importance related to each other, I formulated a “Criterion vs Criterion” matrix. In this matrix I weighted the requirements against each other and calculated the “Relative Decimal Value”.    From there, for each requirement, I calculated the relative decimal value by comparing each project option against each other. Information such as costings (materials, consumables, time, etc.), manufacturing simulation time and machine tolerances were useful for helping estimate the factors.    Using the relative decimal values for each criterion vs criterion and the relative decimal value for each Option vs Criterion, I calculated a Summary Matrix. The Summary Matrix allowed me to completely discard one of the options and focus on the ones with highest value. After meeting with the customer, one of the options was selected. This was based on VoC and practicability.    I have found that the Prioritisation approach is a methodical way of selecting projects; however sometimes additional information or tools are needed when the prioritisation matrix outputs close options. Meetings with customers or considering other factors (such as set-up time, recycling of materials, etc.) can help further select options. | | | | | |
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| Competency | | Business process improvement | | | |
| Performance criteria | | Appropriate use of Six Sigma to support organisational strategy. | | | |
| Understanding the competency | | Describes the origins of Six Sigma. Describes when and where Six Sigma would be an appropriate approach for process improvement. | | | |
| Applying the competency | | Demonstration of the impact that Six Sigma has had on the organisation. | | | |
| Managing the competency | | Not applicable. | | | |
| Training the competency | | Not applicable. | | | |
| Competence statement | | | | | |
| Six Sigma is defined in the ISO 13053-2:2011 as “an approach developed for business and organisations seeking to gain a competitive advantage”. The standard mentions that Six Sigma practices have the goal of: i) driving process improvement and making statistically based decisions, ii) measuring business results with a level of reliance, iii) provisioning for uncertainty and error, iv) combining high returns and benefits in the short medium and long run and v) removing the waste from any process.  However, I see Six Sigma as more than a methodology and a set of theories and techniques that seek to improve processes. I consider it to be a philosophy, a culture, a vision, a way of doing business.  Six Sigma is widely applicable to the AMRC and in general to the Research and Development (R&D) business. An example of the use of Six Sigma tools is for experimentation. R&D businesses rely on carrying out experiments to characterise, optimise and test processes and products. Six Sigma offers an invaluable tool that saves R&D business resources in terms of financial and time. By using Design of Experiments (DoE) valuable time and consumables are saved. DoE is a statistical framework for planning, analysing and presenting experimental outcomes. Moreover, Six Sigma has tools for project planning, managing teams and stakeholders; which in most cases are part of the R&D process.  Another Six Sigma tool that is continuously used I the R&D area is hypothesis testing. Researchers are often questioned to decide between alternatives, or estimate differences. R&D business makes extensive use of experimentation and utilise measurement equipment. Six Sigma techniques such as Process Capability and Gauge Reproducibility and Repeatability are invaluable for understanding these types of assets.  I consider myself as having adopted the Six Sigma “culture” and being able to use (and excel) in some of the tools and techniques that are part of Six Sigma. In particular the project management, problem solving and statistical tools. I have used DoE extensively and have published scientific articles characterising manufacturing systems. I have managed a number of R&D projects, managed teams and stakeholders. | | | | | |
| Associated evidence | | | | | |
| Process improvement is the quest for improving upon existing business processes by identifying analysing and improving tasks within a system or subsystem, with the aim of optimising to operate to their full potential and at higher quality. Six Sigma is a well-defined methodology for process improvement. Improvement, in Six Sigma, generally entails making processes as predictable as possible thus eliminating causes of variation.  The basic statistical principle of Six Sigma has its origin with a German mathematician, Friedrich Gauss who conceived the concept of “Normal Distribution”. In such a distribution the majority of data have similar values and there are few data points that fall outside a reduced range. When plotting the frequency of values the resulting graph has a shape of an inverted u, so called “Bell Shape”. The shape of the distribution can be characterised by two parameters, a measurement of central tendency (the mean) and a measurement of the spread (standard deviation). In a Normal Distribution 68.27%, 95.45% and 99.73% of the data lies within one, two and three standard deviations of the mean. Using this concept, the variability of processes and services (and natural phenomenon) can be assessed by identifying geometrical parameters of the distribution.  The use of Six Sigma as a measurement standard in product variation can be attributed to Walter Shewhart who showed that three sigma from the mean is the point where a process requires correction. Shewhart worked for Western Electric in 1918 when he developed control charts bringing together the disciplines of statistics, engineering and economics. He classed causes of process variation into special-cause and chance-cause.  Edward Deming was one of the adopters of Shewhart philosophy including statistical process control, operational definitions and the ideas of the time of Plan-Do-Study-Act. Deming was a statistician and worked in the Japanese industry where he developed his ideas on statistics for product quality.  The term “Six Sigma” was coined by Bill Smith working for Motorola in the 80s. He started focusing on defects caused by process variation and tried to minimise it. He measured the defects per million opportunities. The sigma rating describes the maturity of a manufacturing process indicating its yield of the percentage of defect-free products. A six sigma process is one in which 99.99966% of all opportunities to produce some feature of a part are statistically expected to be free of defect (3.4 defective features per million opportunities.  Six Sigma has had a big impact in my work at the AMRC. I have used different tools of the six sigma methodology, which have helped the successful completion of R&D and industrial projects. Six Sigma has guaranteed the elimination of defective outcomes and waste. I have incorporated the methodology in my work to project manage, tackle chronic problems, understand process capability, carry out gauge repeatability and reproducibility .  A recurrent example of the impact of Six Sigma methods in the organisation is the use of Design of Experiments (DoE) for characterising, optimising and testing robustness of systems. The technique reflects on the time and physical resources used to understand systems. A single example is when I use DoE for characterising the process of water jetting of carbon fibre polymers. In order to tackle the problem I used a fractional factorial DoE with five variables. I measured two responses (surface roughness and taper angle). The experimental approached allowed me to understand the process, finding relationships (interactions) and main effects. These data was later used to select parameters for an applications project, where the customer required certain criteria to be met. I used the data generated with DoE for optimising parameters to meet the VOC criteria. | | | | | |

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| Competency | | Change management | | | |
| Performance criteria | | Importance of using a coherent approach to change management. | | | |
| Understanding the competency | | Describes the interaction between stakeholders and change process and the mutual impact of one or the other. | | | |
| Applying the competency | | Demonstration of the identification of key stakeholders and the use of coherent approach to process change. | | | |
| Managing the competency | | Evidence of review of Green Belt change effectiveness. | | | |
| Training the competency | | Not applicable. | | | |
| Competence statement | | | | | |
| Process improvement projects may lead to change. The Six Sigma methodology focuses on streamlining processes by bringing innovative changes to the organisation to purse efficiency. For a Six Sigma project to be successful change needs to be managed accordingly in all people involved and affected by the project (stakeholders). Change management is an essential part of Six Sigma as it will aid to overcome organisational roadblocks, conflicts and motivate team members.  A Six Sigma project may impact stakeholders in different ways:   * Process inputs may be altered => changes requirements in suppliers * Process procedures may be updated => impacts operators and managers * Process outputs may be different => impacts customers   In order to manage change, the stakeholders of the project need to be identified. This could initially be carried out by brainstorming an exhaustive list of people / groups / institutions affected by the project. A more structure approach such as mind-maps, Venn diagrams or structure tables can be used to divide the stakeholders in different groups (primary, secondary and tertiary). Poorly managed stakeholders will have a negative effect on the project and may lead to the project failing.  Change management deals with means to plan, initiate, realise, control and stabilise the change in processes in the different levels: individuals, teams, organisations and enterprise. Six Sigma recognises how people are affected by change. People usually go through phases when dealing with change. Initially there is shock and surprise. This is followed by denial and refusal, until they realise and understand the rational for change. The most important phase is the emotional acceptance. Once the change has been accepted a learning step where people learn the new behaviours and processes starts until the change is realised. Finally people totally integrate to change. | | | | | |
| Associated evidence | | | | | |
| An example of successful change was the introduction of new procedures for streaming work orders in my research group. The stakeholders were identified by brainstorming with the research group. A list of stakeholders was produced. Stakeholders were classified according to their importance in the project with the help of a stakeholder analysis matrix.   |  |  | | --- | --- | |  |  |   I followed a change management method based on John Kotter’s 8 step process for leading change:   1. Establishing a sense of urgency: I had a meeting with the research group, who were the primary stakeholders and communicated the need to change, stressing the fact that in order to be competitive we needed to change the way we dealt with work orders. 2. Forming a powerful guiding coalition: I got the team involved in the process. Especially the machine operator. I listened to his ideas and prompted to generate ideas that were already proposed. This empowered him to take ownership of the change. 3. Creating the vision: After the ideas were collected we had a meeting to discuss the vision. The primary stakeholders were directly involved in creating the new workflow. We made some flowcharts which made it more visual. 4. Communicating the vision: After filtering out some ideas and options we came up with a proposed new work order process. 5. Empowering others to act on the vision: We work closely as a team where each one had ownership of a task to achieve the vision. As all the team was aware of how their tasks fitted within the vision, they were motivated to complete their work. 6. Planning for and creating short-term wins: The implementation plan consisted on different stages with milestones which we celebrated once they were achieved. 7. Consolidating improvements and producing still more change: 8. Insitutionalising new approaches: The new approach was consolidated and the new system became the norm of doing things.  |  |  | | --- | --- | |  |  | | | | | | |

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| Competency | | Leadership development in self. | | | |
| Performance criteria | | Importance of delivering leadership skills in self. | | | |
| Understanding the competency | | Describes leadership development, including the following as appropriate: self-assessment, importance of coaching, importance of mentoring, personal development plans. | | | |
| Applying the competency | | Demonstrates identification of any gaps in required, own competencies to progress change and suggestions made for appropriate actions. | | | |
| Managing the competency | | Not applicable. | | | |
| Training the competency | | Not applicable. | | | |
| Competence statement | | | | | |
| Self-leadership entails knowing yourself, knowing your capabilities and limitations. It is having a plan of how you would like to develop and what actions are needed to achieve your objective. “Self-leadership is the process by which you influence yourself to achieve your objectives”.  Continuous personal development is a topic that I am most interest. I try to incorporate it in all aspects of my life: my health, my hobbies, my career and my relationships. I am actively looking for training and opportunities of taking courses to improve my skills. I read books on the topics, browse the internet for articles, blogs and videos. I love Massive Open Online Courses (MOOCs) and have done full specialisations and modules with them. | | | | | |
| Associated evidence | | | | | |
| There are a few techniques that I use for knowing my capabilities and limitations (self-assessment). I often reflect on my actions and performance and provide self-feedback. I keep a diary with lessons learnt. I also take feedback from other people. I have my performance review annually and take this as an opportunity for self-reflection and to ask for detailed feedback. I also enjoy trying new things, as hobbies, projects or career skills; this is a good way to discover my limitations.  Coaching and mentoring is another aspect of leadership and perhaps the one that satisfies me the most. I am a mentor in one MOOCs module (“Reproducible Research”), where I answer to students’ queries and offer advice to them. I have also registered as a mentor of the Monitored Professional Development Scheme (MPDS) for the Institute of Mechanical Engineers (IMechE). With this scheme I have been assigned a developer engineer whom I will mentor for a period up to 4 years to help him develop to obtain Chartered Engineer status. We have had our introductory meeting and we have started working together. I also consider myself a mentor for the research assistants in my team.  I have a Personal Development Plan (PDP) that keep updated. This plan intends to tackle the current limitations that I see from my self-assessment as well as equip me with new skills that I think I will need in the future to progress my career. I have already completed some of my short term goals.  - I have become a Chartered Engineer.  - I have published one journal article.  - I have completed some modules for my MBA.  - I have become a mentor for the IMechE.  - I have contacted new possible partners for the AMRC. | | | | | |

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| Competency | | Leadership development in others. | | | |
| Performance criteria | | Importance of leadership development in others. | | | |
| Understanding the competency | | Describes leadership development in others including as appropriate: assessment, coaching, mentoring, development plans. | | | |
| Applying the competency | | Demonstrates identification of any gaps in required competencies to progress change, in individuals, teams or in the organisation, and suggestions made for appropriate action. | | | |
| Managing the competency | | Not applicable. | | | |
| Training the competency | | Not applicable. | | | |
| Competence statement | | | | | |
| “Adopt and institute leadership” is the seventh point of Edward Deming’s 14 points for Total Quality Management. “The aim of leadership should be to improve the performance of man and machine, to improve quality, to increase output, and simultaneously to bring pride of workmanship to people”. In order to improve performance of systems (machine) leaders have to be equipped with knowledge and information to take decisions follows them through execution, allocating resources and motivating people. Leaders improve the performance of people (man –or women) by helping in growing the capabilities of others by mentoring and coaching.  The identification of knowledge gaps is of paramount importance for the effective personal (self or others) development. This has to be aligned with the overall organisational strategy to be able to map organisational needs with development plans. Identifying learning and development needs can be based on formal and informal assessments which identify current and anticipated personnel capabilities. Creating a development plan assisted by coaching and mentoring allows supporting others in their leadership development. | | | | | |
| Associated evidence | | | | | |
| As a head of a research group, I manage the personal development of my team. I assess their learning needs using an array of tools. In the first instance by analysing their performance in the different areas that they work. We have a lessons learnt meeting each time we finish a project which is a good opportunity to reflect in the issues that could have gone better and identify any knowledge gaps. I also carry out an interview every year to discuss their personal development plan. In this meeting I asked them to reflect in their performance and provide self-feedback on the work they have carried out in the year. I set out a learning plan based on past performance and future group needs. As an example, I identify a gap of knowledge in statistical techniques for my young researcher. I enrolled him on a training course and supported his development by giving him a project where he used his new knowledge. Now he is working with a different team and he has taken control of the Design of Experiments. He asked for my helped to convince his team to follow the DoE approach (rather than varying one factor at a time). He wanted me to talk to his team to convince them. However, instead I provided him with the tools and confidence he needed to convince his team. As a result, his new team are DoE converts.    I am also a mentor in an online Coursera Data Science Specialisation module (Reproducible Research). I virtually mentor people that are enrolled in the course via online forums. I answer their queries and provide information that might be useful for them.    In addition I enrolled to be a mentor for the Institute of Mechanical Engineers (IMechE) Monitored Professional Development Scheme (MPDS), where I was assigned a development engineer to guide him through his first four years of his career. We have had our introductory meeting, where we set expectations and plan how to benchmark his current engineering knowledge. | | | | | |

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| Competency | | Data acquisition for analysis | | | |
| Performance criteria | | Identifying and actively seeking appropriate information in various forms, ensuring the validity of such information and transforming into data which can be analysed in competency 22. | | | |
| Understanding the competency | | Describes where data might be found and possible formats (structured and unstructured) Describes how to verify and validate information and manipulate data into appropriate formats. | | | |
| Applying the competency | | Demonstration of a plan to acquire appropriate date, the verification and validation of such data the manipulation of data into the appropriate format to satisfy project objectives. | | | |
| Managing the competency | | Critical analysis of existing data streams and suggestions of possible improvements. | | | |
| Training the competency | | Not applicable. | | | |
| Competence statement | | | | | |
| Data are quantities, characters, images or symbols that when analysed provide a description of the source. Data help in making decisions, more data generally means less risk in decision taking. The better the data the lower the risk.  Data can come in many forms and can be categorised as structured and unstructured. Structured data is highly organised information that can be put into a database and search through by computerised operations or algorithms. Unstructured data may have an underlying structure however this is not evident and cannot be searched easily with algorithms. Unstructured data are subjective and sometimes heavily based on text or images. Unstructured data can come from documents, presentations, audio, images, videos, messages, books, social media, etc.  There are different types of data. At the highest level, data can be classified into quantitative and qualitative. Quantitative data express a certain quantity, amount or range. It is usually associated with a measurement, unit or count. Arithmetic operations can easily be carried out with quantitative data. There are two types of quantitative data: continuous and discrete. Continuous data can be refined by dividing it into smaller finer levels whereas discrete data refers to a count which typically involves integers.  Qualitative data offers characteristics, properties describing things. Qualitative data cannot be expressed as single numbers. There are three main kinds of qualitative data: binary, nominal and ordinal. Binary data categorises things into two mutually exclusive categories whereas nominal data assigns an array of categories that do not have an implicit natural value or rank. Finally ordinal data divides items into categories that can be ordered according to a rank. | | | | | |
| Associated evidence | | | | | |
| Most organisations collect vast amounts of data which are readily available for analysis. Data may have been collected manually or automatically. Care must be taken when data has been collected manually which might be prone to errors (units of measure, handwriting mistakes, data truncation, ambiguous terminology). Errors of data collection can also come from inadequate or uncalibrated measurements systems. There are a few ways to minimise error in data collection: construct a data collection plan, maintain a calibration schedule, conduct gauge repeatability and reproducibility studies (GR&R), produce templates for data acquisition with appropriate meta data (units, collection time, conditions, equipment used, name of data recorder, etc.), use appropriate statistical tools to identify and address outliers, automate data acquisition.  When collecting data I use a three phase approach specified in the data collection plan: a pre data gathering, data collection and post data. Before collecting the data the goal and objectives of the data collection exercise need to be defined. A brief description of the project with its business justification and the rationale for collecting the data is helpful in deciding what techniques of data collection to use. A plan of how to collect the data can then be made. The plan should include applicable definitions, procedures and guidelines for data collection (random, stratified sampling, etc.) the number of observations needed, time intervals defined. The plan must also ensure that the data is collected in a way that will be repeatable, reproducible and accurate. A GR&R study will ensure this step is covered.    The data collection step can be established once the data plan and procedures are in place. I usually do some trials to see if the system is working and validate the procedures. Improvements can be made at this stage. For instance the use of a different gauge (a GO/NO GO one, instead of a metric one), different measuring fixture, standardisation of procedures (side to measure).  The last step in data collection is to collate all data and do further checks to see if the required data has been captured, are reasonable and meet the criteria of the aims stated. An exploratory data analysis can be carried out where the data are put into a format where it is easy to visualise e.g. charts. This is a quick way to identify missing data, outliers or incongruent data.  During my Black Belt project, I identified problems with acquiring data. Due to the confidentiality of the data all data is managed by central HR. However, looking at the data in detail I found out inconsistencies and suggested a different format to collect data. The data were in the form of pivot tables which presented summary of data. I disaggregated the data and analysed it in “R software”. I found out that data was missing and some variables were aggregated / disaggregated wrongly. For instance, the data from the AMRC was disaggregated into three groups instead of two (AMRC with Boeing and Nuclear AMRC). Data for NAMRC for the period of 2017 were missing.  I had a meeting with HR to change the format of the data. I also liaise with the training department in order to modify the way we collect data for training courses. | | | | | |
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| Index | 6.1 | Table | B.2 | Original index | 10 |
| Competency | | Analysis of Data | | | |
| Performance criteria | | To be able to select and apply the correct tools for analysis | | | |
| Understanding the competency | | Can describe different tools and when they are used (for example Ishikawa’s seven quality tools). | | | |
| Applying the competency | | Has evidence of the correct selection and use of appropriate analysis techniques | | | |
| Managing the competency | | Manages the use of appropriate techniques in Lean & Six Sigma implementations | | | |
| Training the competency | | Trains appropriate analysis techniques, for example, Ishikawa’s seven quality tools. | | | |
| Competence statement | | | | | |
| There are various techniques for data analysis; some of them are based on advanced statistics. However, there are also basic visual techniques for data analysis. These have the advantage of being simple, easy to use and understand and can solve a variety of issues. Ishikawa put together seven tools to assist in problem solving and process improvement. These are referred to as the “Seven Basic Tools of Quality”. These are:  1. Cause-and-effect diagram: Useful for identifying the various factors leading to an effect; identify root cause behind a problem. The sources of variation are identified by grouping them into six categories (people, methods, machines, material, measurements and environment).  2. Check sheet: A structured form used to collect data (qualitative or quantitative) in real time. When the data is qualitative the check sheet is often referred to as “Tally Sheet”. This tool is useful to keep records, quantify defects, understand the progress, and identify defect patterns and possible causes for defects.  3. Control charts: Graphs used to study how a process changes over time. Control charts use statistics to determine if a process is stable and capable within current conditions. Control Charts have a central line (average or mean), an upper line for the upper control limit and a lower line for the lower control limit. Data are plotted against time in X-axis. By analysing the graph conclusions whether the process is in control or out of control can be drawn.  4. Histogram: Represent the distribution of data by plotting the frequency of occurrence to indicate how often each different value in asset of data happens. By looking at the distribution measurements of central tendency can be spotted as well as the spread of the data.  5. Pareto Chart: Used to highlight the most important set of factors by plotting the individual factors in descending order in bars and a line showing the cumulative total. Pareto charts are good at distinguishing between “vital few and trivia many”, display relative importance of causes of problem, help focus on causes that will have the greatest impact.  6. Scatterplot: Show the data in two dimensions by plotting a variable and its effect in two axes. Scatterplots are useful for identifying correlations visually.  7. Stratification: A technique that separates data gathered from a variety of sources so that patterns can be seen. The population is divided into different groups where data are collected by systematic sampling, reducing the sampling error. | | | | | |
| Associated evidence | | | | | |
| I have used the seven tools of quality in different projects. I used the cause-and-effect diagram to investigate a problem with a manufacturing process. The parts that we were cutting came out of tolerance. We needed to investigate the root cause in order to tackle the problem. After brainstorming we came up with the following diagram:    I have used check lists to gather data in real time regarding machining problems while producing a part. I was cutting pockets in a cylinder using an abrasive water jet machine. Sometimes the abrasive flow was restricted and sometimes the machine would stop. I used a check list to record occurrences and try to find patterns and relationship to part quality.    I used a histogram to identify the gender makeup of the AMRC. I collected data on the number of staff each year and their gender. I plotted the data for frequency in each year. For better visualisation I presented the results as a percentage. In this way I could find out that the gender makeup of the AMRC has remained constant (around 24% female) despite the growth in staff numbers.    I have used the Pareto Chart to identify the issue that has higher recurrence. I had a problem with the water jet machine. The machine would stop while cutting and an error displayed in the controller. I recorded the frequency of error occurrences and created a Pareto Chart. The information was passed onto the machine manufacturers to see if they could address the issue.    A scatter plot proved useful when investigating the premature failure of samples. I was testing a new process where we were replacing the manual operation of deburring with an automated one. I created some fatigue samples with a feature deburred automatically using a brush. It turns out that some samples were failing prematurely. By plotting the fatigue life versus the order of machining, I found out that the life of the brush had an effect on fatigue life. The brush “as new” was too abrasive and was scoring the feature, when the brush wore down, fatigue life increased.    I have provided informal training on data analysis, especially on Design of Experiment, which I consider myself an expert. Apart from training my research assistant and students I have provided support for people from different groups. An example is supporting the “Process modelling” group to design experiments for their project. The team had limited resources in time and material for carrying out their experiments. They consulted me to see if I could help them choose the best DoE for their resources and objective. I had a meeting with the team leader and explained the difference in DoE objectives (characterisation, optimisation, robustness testing) and the different models that they could build (linear, interactions). After the meeting he had more knowledge about DoE and was able to choose his experimental design. | | | | | |
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| Competency | | Creative thinking | | | |
| Performance criteria | | To apply creative thinking approaches to define and pursue project and Lean objectives | | | |
| Understanding the competency | | Can describe the different thinking modes (e.g. creative and analytical, divergent / convergent) and suggest appropriate techniques to support creative thinking. | | | |
| Applying the competency | | Evidence of use of this approach during the project. | | | |
| Managing the competency | | Critical analysis of suitability of chosen approach. | | | |
| Training the competency | | Train others in creative thinking approaches. | | | |
| Competence statement | | | | | |
| Creative thinking is approaching problems in an atypical way, coming up with solutions outside the norm. Creative thinking can be stimulated by unstructured and structured processes. There are two types of thinking: convergent and creative. Divergent thinking involves the ability to generate multiple ideas with fluency and speed. Divergent thinking is: creative, generative, intuitive, emotional diffuse. Unstructured processes such as ideating and brainstorming can stimulate divergent thinking. Convergent thinking is the ability to use logic and analytical skills in evaluating possible solutions to narrow down ideas to arrive at a solution for a given problem. Convergent thinking is: Analytical, sequential, rational, focused, objective.  Creative thinking involves four stages:  1. Preparation. Formulate the problem and acquire as much knowledge and information as possible.  2. Incubation. Process the information gathered. Make connection.  3. Illumination. Sudden flash or idea. Eureka moment.  4. Verification. Evaluate the validity of the solution. Use analytical and critical skills.  There are various techniques that can be used to aid creative thinking:  - Brainstorming: Generate as many ideas as possible without criticising, thinking aloud. If the process is done in two steps, writing ideas individually and then sharing them to generate more ideas, the process is sometimes called Brainwriting.  - Lateral thinking: Generate ideas by looking at things in a different perspective, change concepts and perceptions.  - Six thinking hats: Thoughts are focused according to six roles by “wearing” a colour hat. . Factual information is represented by the white hat. The yellow hat explores positives and probe for value and benefit. The black hat is judgment. It spots the difficulties and dangers. The red hat signifies feelings, hunches and intuition. The green hat focuses on creativity, possibilities, alternatives and new ideas. The Blue hat is used to manage the thinking process. It is used as a control mechanism to ensure that guidelines are observed.  - Checklist: Asking questions of why? Where? When? Who? What? And How? Every time a new idea is proposed.  Random input: Applies random words, pictures or even sounds to help think of new connections. | | | | | |
| Associated evidence | | | | | |
| I have used creative thinking to come up with innovative solutions as part of a group or individually. When tackling a new research project I usually have a group meeting and go through the process of brainstorming to explore ideas. Then I narrow down the list and look for novel solutions. I often complement this list with ideas generated by lateral thinking techniques such as image and word association.  An example was when I designed a fixture. We used the brain writing technique; words written in pieces of paper were used to help with the selection of features to include. After the ideas were accepted we went through a verification method to assess the ideas for various aspects such as feasibility, difficulty, economy and health and safety.  Within my group I motivate researchers, students and operator to use critical thinking. Apart of using brainstorming for every single problem solving I motivate them to do a checklist asking why? Where? When? Who? What? How? Plus the question is it safe? Which I added to satisfy the Health and Safety requirements.  We used this approach for solving a problem while cutting an aperture in a cylinder with an Abrasive Water Jet. After cutting the aperture, the water jet had to be stopped to avoid damaging the other side of the cylinder. After a brainstorm process that generated a list of possible options I asked the team to ask the questions in the checklist. This helped discard unfeasible solutions. | | | | | |

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| Index | 8 | Table | A.2 | Original index | 8 |
| Competency | | Costumer focus | | | |
| Performance criteria | | To understand how and why to listen to and capture the “voice of the customer” (VOC) | | | |
| Understanding the competency | | Describes the different types of customers. To understand the link between the VOC and the requirements of other stakeholders, e.g. operations and management. | | | |
| Applying the competency | | Demonstration of the application of ‘customer focus’ approaches. For example, through the correct use of the Kano model and ‘house of quality’ and/or ‘critical to’ (CT) matrices. | | | |
| Managing the competency | | Reviews effectiveness of solutions to address customer’s needs. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Customers assess the quality and value of a product or service. Successful quality improvement projects achieve cost savings and improved customer relationships through an understanding of customer needs, wants and requirements; the voice of customer. VOC is “a complete set of customer wants and needs; expressed in the customer’s own language; organised the way the customer thinks about, uses and interacts with the product and service; and prioritised by the customer in terms of both importance and performance”.  The VOC can be captured in a variety of ways:   * Surveys * Interviews * Focus Groups * Suggestions * Observations * Customer specifications * Complaint logs * Social media   A customer is a person who buys or uses a product or service; the receiver of the process output. Customers can be broadly classified into two categories:   * Internal customers are the ones that are affected by the product or service as it is being generated. They are the managers, employees or people from functional departments within the organisation. * External customers are not part of the organisation. They are the ones who use the product or service you produce or have vested interest in the organisation and provide the major portion of company revenues. They are the end-users. | | | | | |
| Associated evidence | | | | | |
| I have used different techniques to “listen to the VOC” for internal and external customers. For internal customers (AMRC Staff), I have used questionnaires and focused groups. I used a google questionnaire to find out AMRC partners (external customers) regarding their technology needs. The questionnaire allowed me to better understand stakeholder requirements.    I have used questionnaires for listening to the VOC for internal customers (AMRC staff). The questionnaire allowed to understand AMRC’s staff views on gender and diversity.    I have used the “House of Quality” technique from Quality Function Deployment to translate the VOC into engineering characteristics. This helped to understand customer requirements and to relate to the importance of engineering options. Additionally the relationships between these options are analysed.    The HoQ allowed me to find out what the most important features for the fixture design were, according to the VoC. The emphasis on the design was on a high tolerance / low cost fixture with easy access for inspection methods. The tolerance of 0.25 mm was also stressed by the HoQ approach. Another output of the HoQ was understanding the relationships between the quality characteristics. For instance, accuracy was strongly related to number of datum points, board spacing, material thickness, joining method and fixture material. It made evident that if we wanted an accurate fixture we needed to optimise those factors. | | | | | |

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| Index | 9 | Table | A.2 | Original index | 9 |
| Competency | | Decision making and taking | | | |
| Performance criteria | | To recognise the importance of decision taking and identify the decision takers. | | | |
| Understanding the competency | | Describes circumstances where decision taking is required and the responsibility for these decisions. | | | |
| Applying the competency | | Demonstration of the appropriate usage of the key elements of decision-taking (individual or group). | | | |
| Managing the competency | | Review of effectiveness of decision making processes. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| In a globalised environment, where often businesses offer similar standards, decision making is becoming a competitive advantage. Effective decision making can create value in organisations. Effective decision making is the process through which alternatives are selected and managed through implementation to achieve a desired objective. Effective decisions are a result of a systematic process going through a set of steps. Decisions can be taken by single individuals or groups. The decision maker has to have the authority to make decisions.  DACI is a model for decision making that clarifies who has the authority of a project stakeholder to make decisions. The name comes from an acronym of the four different roles in a six sigma project. Drivers handle the overall coordination of the project, meeting, or business. The Driver has responsibility for communicating with other team members and ensuring that roles and responsibilities are clear. The project manager is usually the driver in a project. Approvers may or may not be involved in the detail work of the project team, but their approval is required for key decisions. Contributors are people that must be consulted to provide input for certain types of decisions. Often a contributor does not have the authority to take decisions but their area of operation affect the work of the project team. Informed are people that do not necessarily have a role in the project but must be kept informed once decisions are made. There are other models for assigning responsibilities to stakeholders such as RACI where R stands for Responsible.  Several decision making tools are available for individuals and groups to aid with the decision making process:  Force Field Analysis is a tool used to summarise information regarding obstacles and drivers for achieving a certain aim. It uses a table where at the top the goal or “future state” is worded. Then two columns listing the “driving forces”, the things that will help make the future state occur. The second column, restraining force, provides a list of issues that will prevent the future state from occurring. By comparing scores of FOR/AGAINST options a decision can be made.  Pugh matrix allows teams to compare options using a simple rating system. The team members establish a list of criteria and assign weights to each based on its importance for achieving project goals. A comparison is made against a standard which could be the current situation. The team assesses if the option is better or worse than the standard. The total for each option calculated based on the weights and ratings determine the best choice.  Multi-Voting is a group decision making technique where team members are given 100 points to allocate to the options that are been discussed. They assign the largest amount of points to the option they feel is best. A sum of points for each option determines which one is the best.  Failure Modes and Effects Analysis (FMEA) is used for risk assessment and weighing different options for process improvement. Team members list the possible problems that could arise under each scenario and assign ratings to estimate how likely each problem is, how severe it would be and how easily it could be detected before having an impact. Based on combined ratings, the team can determine which solution is best and which potential risks or implementation must be addressed.  Nominal group technique (NGT) is used in a group to rank items. Each member of the group provides a nominal score to each of the items providing an individual team member ranking. A general team ranking is obtained by adding the individual rankings.  Conversion/diversion uses two modes of thinking types to arrive at a decision. Diversion is used to generate a pool of ideas with techniques such as brainstorming listing possibilities in a cause and effect diagram. Then conversion techniques such as NGT and multi-voting are used to narrow down the list and assign priorities or rankings to the options.  The chances of the decision taken, be implemented and effective are higher if the stakeholders are considered and take part on the decision making process. An implementation strategy will increase the chances of success. The effectiveness of the decision can be assessed by performing surveys with customers and stakeholders, documenting the change and looking at feedback. | | | | | |
| Associated evidence | | | | | |
| I take decision at each step of the project from initialisation to project closure. In order to identify the decision makers (responsible, accountable, consulted and informed). I have used a RACI matrix. This allows me to identify inputs for decision making and people affecting the decisions, who should be kept informed.    I have used different tools and techniques for decision making. I have used a Force Field analysis to weight between change proposals. When pondered with the choice between two machining systems, I carried out a Force Field Analysis in order to explore the options.    I have used Failure Mode Analysis in order to explore the different potential failure modes and their consequences. Understanding failure modes and their impact in the project allows devising and implementing control methods, allocating responsibilities and actions.    For decision making to be effective it is necessary to gather as much information as possible. This can be done by consulting the stakeholders and experts in the area. Then use techniques such as brainstorming , NGT, decision trees, scenario analysis techniques to assess options. The decisions taken have a big impact on project outcomes. This can be seen in “Lessons Learnt Documents” where the results of the decision making process can be weighted. For instance, the decision of use a different CAM software resolve an issue of programming and led to a successful outcome. Whereas the decision of using a wooden fixture led to cutting a panel out of tolerance. Analysing decisions outcomes is an opportunity to reflect on the decision making process and improve for next scenarios. | | | | | |
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| Index | 10 | Table | A.2 | Original index | 10 |
| Competency | | Interpersonal and team leadership skills. | | | |
| Performance criteria | | To support effective interaction with others including stakeholders. To work effectively with others to achieve objectives. | | | |
| Understanding the competency | | To describe the factors affecting team effectiveness, including factors such as leadership style, team roles, personality types. | | | |
| Applying the competency | | Demonstration that the Black Belt has studied their team from the viewpoint of the interpersonal skills deployed, taken appropriate action and demonstrated a positive effect. | | | |
| Managing the competency | | Review of effectiveness of actions. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| There are two general types of team: informal and formal. Formal teams have defined purpose and goal linked to an organisational strategy. The members of the team and their roles and responsibilities are often documented. Informal teams have a more lose approach with no hard boundaries of their structure and relationships.  Teams can also be classified according to other characteristics such as geographical location. Virtual teams are made up of people with different locations which make use of communication technology to work together. Teams that have established missions can be self-directed, looking at one ongoing mission or specifically process improvement teams.  The composition of the team may vary according to its function and objectives. A number of nine different roles have been identified as essential for the success of a team. Individuals tend to have certain trends that make them more suitable for certain types of roles. A Six Sigma leader has to recognise those traits in the team members in order to allocate roles and responsibilities. An effective team has to have a balance of these roles. Personal attributes that enable a person to make a particular type of contribution also create weaknesses that must be accommodated.   |  |  |  | | --- | --- | --- | | Role | Trait | Weaknesses | | Plant | Creative, imaginative, free-thinker. Good at solving problems in unconventional ways. | Absent-minded, forgetful. Might ignore incidentals, and may be too preoccupied to communicate effectively. | | Resource Investigator | Extrovert, enthusiastic, communicative. Finds ideas to bring back to the team. | Over optimistic. Can lose interest once the initial enthusiasm has passed. | | Coordinator | Mature, confident. Focuses on team’s objectives, draw out team members and delegates work. | Can be seen as manipulative and might offload their own share of work. | | Shaper | Challenging, dynamic. Drives the team to move forward and not lose focus. | Can be prone to provocation. May sometimes offend people feelings. | | Monitor Evaluator | Sober, strategic, discerning. Provides logical thinking, makes impartial judgements, weighs up options. | Lacks the ability to inspire others can be over critical. | | Team Worker | Cooperative, mild, perceptive, diplomatic. Helps the team to get tasks done. | Can be indecisive in crunch situations and tend to avoid confrontation. | | Implementer | Disciplined, reliable, conservative, efficient. Plans workable strategy and delivers it efficiently. | Can be a bit inflexible and slow to respond to new possibilities. | | Completer Finisher | Painstaking, conscientious, anxious. Used at the end of the task to polish and scrutinise the work for errors. | Can be inclined to worry unduly and reluctant to delegate. | | Specialist | Single-minded, self-starting, dedicated. Brings in-depth knowledge of a key area to the team. | Tends to contribute on a narrow front and can dwell on the technicalities. |   Teams go through several group development stages. The team development stages can be linked to leadership strategies:   * Forming: Members do not fully understand the goal of the team and their individual role. Team members do not work together. Discussion focuses around defining the team goal, tasks and members roles. A strategy that leaders have to adopt is to coordinate behaviours, facilitate the team to identify goals, assign roles and responsibilities. * Storming: Members form their own opinions about each other and their participation in the team. Participants often disagreeing with others; there is conflict. A leadership strategy is to coach behaviours, act as a resource person to the team, develop mutual trust and calm the work environment. * Norming: Team members resolve their disagreements and begin to work as a team. A share common goal usually joins team members. Leadership strategies allow empowering behaviours and transfer of leadership. * Performing Team members work together to achieve objectives. This phase is where high performance is achieved. Leadership is concerned to supervising and taking decisions. * Adjourning: Loose ends are tied up, final tasks completed. The team is dissolved. Leadership can focus on creating future leadership. * Recognition. Team contribution is acknowledged.   Without good leadership a team can backslide from norming or performing into a previous stage. Leadership can also accelerate the progress of the team for instance by avoiding the storming stage. Successful Six Sigma project team leaders must complement their analytical with interpersonal skills. Leadership skills and effective team performance are key elements in the Six Sigma philosophy. Six Sigma programmes are integrated into the company’s culture and strategy through team leadership. Team leadership can improve the quality of thinking that forms strategy and has a direct impact in the ability of the team to carry through on its commitments (execution). Leaders drive higher levels of performance by increasing trust, facilitating the sharing of knowledge, generating synergistic solutions and innovation through productive problem solving and high performance teamwork.  An essential set of interpersonal skills is needed by Black Belts to realise success:   * Communication: which covers verbal and non-verbal and listening . * Negotiation: working with others to find a mutual agreeable outcome. * Emotional intelligence: being able to understand and manage your own and other’s emotions. * Team working: being able to work with others in groups and teams, both formal and informal. * Conflict resolution and mediation: working with others to resolve interpersonal conflict and disagreements in a positive way. * Problem solving and decision making: working with others to identify, define and solve problems, which include making decisions about the best course of action. * Time management: planning and exercising control over the amount of time spent on specific activities, especially to increase effectiveness, efficiency or productivity. * Accelerating change: managing change by building awareness and desire of continuous improvement projects, making people aware of the benefits of change and managing stakeholder’s expectations. * Coaching: provide direction, mentoring and training a person or a group of people with the aim of developing a specific skill. | | | | | |
| Associated evidence | | | | | |
| I manage a group of three people, a research assistant, a researcher student and an operator. We work together to solve problems and get tasks done. I distribute tasks and manage the group considering each individual’s personalities. We often work with other people from other teams in some projects. When this happens I try to manage the group development stages and try to accelerate the team development to a performing stage. I do this by assigning team roles and distributing tasks.  I am an “Implementer”, able to take colleagues’ suggestions and turn them into positive action. I am discipline, reliable and can be trusted to always finish tasks with a high degree of quality adhering to budget and time. I am a good communicator, highly emotional intelligent and aware of cultural differences. I am good at time management, always finishing the tasks in the allocated time. I am goal driven. I am motivated by achieving success in the challenges I am involved and by personal development. I am a good mentor and coach. I am a team player that likes to work in an environment of camaraderie and like to share my skills with the team.    The research assistant is a “Team Worker, he is very helpful in getting things done. He cooperates with the team and does not like confrontation. He is diplomatic. His weakness is that he can be a bit indecisive and needs further guidance. I am aware of this limitation and I offer him support in the form of guidance for backing his decisions.  The operator is a “Plant”. He likes to come up with solutions to problems in an unconventional way. He uses his technical skills to solve problems, sometimes ignoring other details. He is not very good at communicating things. He is good at problem solving.  The research student is a “Resource Investigator”. He likes learning new things, consulting different sources to find out ideas and relate them to the problem under investigation. He is over optimistic and can lose interest easily. He comes up with innovative ideas.  An example of team work was when we had the problem of piercing composite materials with a water jet machine. We had an initial brainstorming session where a list of ideas was produced. After that the research student came back with the advantages and disadvantages of the methods suggested. The research assistant further developed one of the ideas, considering the information provided by the student. With help of the operator they designed the mechanical system to be incorporated on the machine.  After the system was in place we had a meeting to decide how to test the mechanism. We put together a Design Of Experiments to characterise the system. The tests were successful and we used the system to pierce through carbon fibre.  Extract from report: | | | | | |

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| Index | 11 | Table | A.2/B.2 | Original index | 11/13 |
| Competency | | Motivating others | | | |
| Performance criteria | | Understand how to motivate individuals and teams to progress towards objectives. | | | |
| Understanding the competency | | Describes possible approaches such as identifying individual drivers, creating shared vision, shared goals, understanding appropriate incentives and consequences. | | | |
| Applying the competency | | Demonstration of how such approaches have been deployed and the outcomes. | | | |
| Managing the competency | | Review of success of motivation approaches. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Motivated employees results in enormous competitive advantage for those companies with the strength of leadership to manage for real long-term results. Enthusiastic employees welcome change, lower absenteeism and turnover rate, improve things, and encourage co-workers to high levels of performance. Motivation can create an environment that fosters teamwork and collective initiatives to reach common goals and objectives. Motivation can affect project outcomes in terms of cost, quality and time.  An important aspect of being a leader is motivating people throughout their tasks. There are a variety of ways that leaders use to motivate people.   * Identify the team member drivers and motivators; their passion about the work. Assign a role or tasks related to this interest. * Define the organisations vision, mission and strategy as well as the goals and objectives of the projects. Make sure everybody identifies what their key role is to achieve the goal. Ensure each employee is in alignment towards the overall strategy so the group can work as a team and help each other out. * Make employees part of the decision process. Keep motivation through implementation is more likely if employees feel they are part of change initiation. * Empower employees to succeed by delegating challenging and meaningful work. * Allow for learning and development opportunities. Help employees to create their own personal development plan. Be a mentor and a coach. * Monitor progress of employees and provide rewards and recognition of achievements. Make use of positive reinforcement. Recognition can be in form of letters, public expression of appreciation via meetings, newsletters or social media. * Reward employees with outstanding performance, offer monetary rewards, extra time off, trophies, tokens, etc. * Treat employees fair and equal. Equity in wages, benefits job security, safe working conditions and respect and treatment. * Maintain an environment of camaraderie.   There are various motivational theories that leaders can rely on.   * McGregor’s theory X and theory Y: Identifies two opposite behaviours in team members. Theory X classifies individuals that required constant attention, do not want to work, need punishment to achieve desired effort and avoid added responsibilities. Managers will dictate decisions and team members will perform as little as possible to carry out the tasks without punishment. On the other hand, theory Y, classes team members who want to work, find their job satisfying, seek constant opportunities for improvement and are participative. A environment of camaraderie will be form between the manager and team member; working together to achieve objectives. However, team members can change through time and tasks from X to Y. The advantage of this approach is that the differences between team members will be identified. The disadvantage is that leadership and management of two different strategies might be difficult and might seem unfair for the two classes. * Herzberg’s KITA motivation theory is based on the idea that both positive and negative external motivators exist. Managers rely on “carrot” and “stick” method to drive success. KITA inspires a competitive work environment that creates a parent-child relationship between manager and team members and creates both winners and losers. Team members compete for the carrot while trying to avoid the stick. The main advantage of this method is that it provides a degree of control for the manager. It disadvantages form creating a division between manager and team members and between team members themselves. * McClelland’s achievement, affiliation and power motivation. Identifies three motivation modes:   *Achievement motivation* theory is driven by a need to succeed. Individuals like to achieve goals, have personal ambition, take pride on what they do. They like to work towards defined goals and create a course of action towards achieving the goal. Self-motivated individuals are able to perform individually or within a team. The advantage is that they individuals are self-sufficient, they are good at setting themselves goals, define the vision and way to get there. However, they might not accept failing or known when to quiet.  *Affiliation motivation* is driven by relationships and a need to work well with others. Individuals find motivation through a friendly working atmosphere and form a united team. It advantages from having a harmonious environment where the team contributes together to achieve objectives. However individuals that work in tasks where there is no interaction might struggle to get motivation.  *Power motivation* is driven by the ability to dominate and manipulate goals, directions and decisions. Individuals that are motivated by power want to participate in challenging tasks, take decisions and risk. They want to be leaders. There is the advantage to delegate activities to individuals with leadership tendencies; with the disadvantage of challenging authority.   * MBTI Personal style provides a framework to identify personal style based upon a questionnaire. It classes people according to four common traits: need for personal contact with others, application of realism, ability to apply logic and influences of judgment. Knowing the type of person a team member is allows managers to select a motivation approach, tailor the level and content of project information. This advantages from an individualistic motivation technique however, it may be difficult to implement especially without the initial personality assessment. | | | | | |
| Associated evidence | | | | | |
| My team consists of a Research Assistant (RA), a Research Student (RS) and a Machine Operator (MA). I have relied on different methods and techniques for motivating them.  - I have identified their drivers and assigned responsibilities accordingly. The RA is driven by personal development. He enjoys learning new things. The RS is driven by success and being creative. He enjoys having his ideas implemented. The MO enjoys having responsibility. He wants to be in charge. For the RA I assigned the role of machine programmer and parameter developer. I enrolled him into a course of CAD / CAM and a Design Of Experiments course. He really appreciated this and kept him motivated. Additionally, I mentor him for further development. With regards to the RS  - I have defined the group’s mission, goals and strategy. Additionally, for each project we have a meeting to define objectives and strategy.  - Make group members part of the decision process is an important part of the techniques I use to motivate the team. If they are part of the decision, the process of implementation is facilitated. They feel that it is their project and the outcome their success. Each time we are solving a problem we get together to brainstorm and vote for the best solution. We work as a team.  - Monitor progress and provide reward. I supervise progress of the group and have provided reward for successful outcomes. For instance, we were dealing with a complex difficult project where we had to machine a full airplane wing. We had limited time. In order to finish the job we had to work extra time. As a reward when working late I bought the team pizzas and we had a bit of a social. I also rewarded the team with extra time off once we finished the job order. This was especially appreciated by the MO.  - I have tried to maintain an environment of camaraderie. As a team we have a minute to discuss our days and life interest. We have two team breaks a shift where the MO prepares coffee for us and we sit and talk about things not related to work (although sometimes we shift to work things).  I have relied on the McGregor’s motivational theory for motivating team members. Under this framework I identified the team members that belonged to the X and Y categories. I used different motivation techniques for each team member category. For the X member (MO), wanting to do as little work, I used a more autoreactive approach providing rewards (in the form of extra free time) and recognition when they outperform and achieved objectives. I tried to motive him by including him into the decision making process and often making him believe that the ideas to carry out a task in a certain way was his. With this sense of ownership I managed to motivate X type of team member (MO).  For the Y category (RA and RS) I used a different approach. The team members are more motivated for their own success and want to develop further, they take challenges. For these individuals, apart from recognition and rewards (to be fair), I function more like a mentor and a coach. I provided challenging activities and helped them with their personal development plan. These individuals like to be more involved into knowing the details of the projects and ultimate strategy. | | | | | |

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| Index | 12 | Table | A.2 | Original index | 12 |
| Competency | | Numeracy | | | |
| Performance criteria | | To be proficient in interpretation and manipulation of numbers. | | | |
| Understanding the competency | | Describes the necessity to have proficiency with numerical information to undertake a Six Sigma project. | | | |
| Applying the competency | | A demonstration of the sense of the size of order of magnitude and the sound basis of these. To calculate accurately a range of calculations. To recognise when it is appropriate to use a computer and be able to do so effectively. To demonstrate that calculated results are reasonable. To demonstrate interpolations and predictions from the data in projects, e.g. graphs, diagrams, charts and tables. | | | |
| Managing the competency | | To demonstrate that they have assessed numeracy skills in Six Sigma projects, identified gaps and ensured these are addressed appropriately. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Identifying and quantifying process variation is important in Six Sigma methodology. In processes, as in nature, small variations from instance to instance, measure to measure; exist. Basic numerical skills are needed in order to understand and quantify such variations. Descriptive statistics visualisation tools, such as a histogram, can be plotted by aggregating values of metrics acquired on features, relative to their frequency. For a stable “normal” process we would obtain a bell-shaped curve.  Six Sigma uses inferential statistics by looking at a subset of all the data that could be gathered from all process; that is a sample of the population. Different statistics can be calculated and predictions made using only the data from the sample. The confidence in the correctness of that prediction is dependent upon the size of the sample and the behaviour of the data.  The average value of the sample data is called the mean or X-bar. This can be calculated by the addition of all the data points divided by the number of data points ( ). The most common measure of variability is the variance. The variance is calculated by taking the square and adding the deviation of the individual data points from the mean ( . The square root of the variance is the standard deviation, *s*. The standard deviation quantifies the amount of variation or dispersion of a set of data values and is in the same units as the original data.  The mean and standard deviation of the sample are used to estimate the same statistics of the whole population which are then denoted μ and σ, respectively. The mean is a measurement of central tendency of the data and the variance (now calculated) a measurement of the dispersion of the population.  The mean can be transformed by reducing it to zero. That is shifting all the values of the data points to zero by subtracting the mean. The data can also be scaled, so that it has a variance of one, by dividing each value by the standard deviation. This process is called standardisation. A new bell-curve can be built where the area under the curve represents 100% of the possible observations. The curve is symmetrical about the mean and the tails extend to infinity. The area under the curve represents probabilities. The area defined by ±1σ contains 68.28% of the total population, with ±2σ encompassing 95.44% and ±3σ 99.73%. This means that if the boundaries are set to ±3σ then 99.73% of the product/process will be within specification and 0.27% will be outside specification. When a million parts are considered, the defective parts will be 2,700.  https://upload.wikimedia.org/wikipedia/commons/thumb/8/8c/Standard_deviation_diagram.svg/400px-Standard_deviation_diagram.svg.png  Six Sigma Black Belts use basic mental calculations. For instance when calculating process performance metrics. To calculate these we need to differentiate between defective parts and defects in parts. One defective part can have multiple defects. A nonconforming unit is a defective unit. A defect is a non-conformance in one of many possible quality characteristics of a unit that causes customer dissatisfaction.  Percent defective is the percent of parts having one or more defects i.e. how many parts are defective per 100 parts. For example 2% is 0.02 x 100 = 2 parts per lot of 100. Parts per million (PPM) translates the percentage to one million parts 0.02% x 1’000,000 = 20,000 PPM.  A Defect Opportunity (DO) is any possible defect that is important to the customer, causes dissatisfaction and does not satisfy requirements. DO can be present in any type of process, product, or service, but are restricted to those that are critical to customer. The number of DO relates to the complexity of the unit. For example if a unit has 5 parts and in each part there are 3 opportunities of defects then the total DO are 5 x 3 = 15. Considering the DO, which are hypothetical, we can calculate the actual Defects Per Opportunities (DPO) by dividing the number of actual defects by DO. If there are 15 DO and we consider 10 units and find there are 2 defects then DPO = 2/(15 x10) = 0.0133.  We can translate the DPO to Defect Per Million Opportunities (DPMO) by multiplying DPO by one million e.g. 0..0133 x 1000000 = 13333. There is a direct relationship between DPMO and sigma level. For any DPMO a six sigma level is defined. Six Sigma translates to about 3.4 DPMO or 2 defects per billion.  Six Sigma capability metrics include short and long term. Short-term capability is measured at the process validation phase and is usually measured within ±6σ. Long-term capability assumes that the process mean will shift over time around ±1.5σ. Hence, Six Sigma variability will stay constant over time at ±4.5σ that translates to ~3.4 DPMO (pnorm(-4.5)\*1000000) | | | | | |
| Associated evidence | | | | | |
| Six Sigma is founded in probability and statistic concepts which I am proficient in. I have successfully completed a Data Science Specialization from “The Johns Hopkins University” via Coursera with modules such as: Regression Models, Statistical Inference and Practical Machine Learning.      Six Sigma projects might entail calculating different metrics such as sigma level, process potential, process capability. I have used my numerical skills to carry out such analyses. For instance I have used process capability to assess the feasibility of water jetting pockets in casings.    I have built regression models for understanding and modelling the process of water jetting. By quantifying the taper of cut in a water jet process, compensating for machine inaccuracies is possible. I collected data from the process and build a regression model that allows to quantify the taper at a given machine parameter. These data was used to compensate the tool path in real time. | | | | | |

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| Index | 13 | Table | A.2 | Original index | 13 |
| Competency | | Practical problem solving (opportunity realisation) | | | |
| Performance criteria | | The ability to differentiate between different types of problems / opportunities and choose appropriate approaches to address them. For example, acute / chronic, or special cause / common cause.  To understand how and when to apply root cause analysis techniques to identify causal factors for process improvement. | | | |
| Understanding the competency | | To describe appropriate processes used to address different types of problems. Describes where this is appropriate. | | | |
| Applying the competency | | To demonstrate the appropriate use of DMAIC and other problem solving methods, qualifying the selection. To complete process improvements having found the principal root cause and evaluated the cost associated with implementation compared to the cost of the problem itself. To demonstrate the successful choice and application of various practical root-cause identification and sorting techniques (e.g. the five “whys’, Pareto charts, fault tree analysis, cause and effect diagrams). | | | |
| Managing the competency | | To review effectiveness of problem-solving within project team(s). | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| The aim of the Six Sigma philosophy is to improve processes in order to meet customer expectations and remain competitive. Six Sigma methodology is best suited for resolving chronic rather than acute problems. An acute problem is a sudden severe change of expected outcome whereas a chronic problem persists over time. Acute problems are better dealt with by other purpose problem-solving methods such as 8D. For chronic problems, a systematic approach to identifying the root cause, root cause analysis (RCA), needs to be taken.  There are several RCA approaches such as:   * 5 Whys: is a technique that intends to go through the chain of cause-and-effect to arrive at a root cause of the problem by asking Why did this occur? a series of time. * Pareto Chart: use to prioritise potential root causes by counting the frequency of issues occurring. The purpose is to identify the “vital few” from the “trivial many”. The issues are plotted independently in the x axis in form of bars; each bar height is proportional to the number of defects. The right y axis represents the percentage of defects. The cumulative percentage of each defect is graphed above the bars in the shape of a line. * Fault tree analysis: helps identifying all relevant events and conditions leading to undesired events, determines parallel and sequential event combinations and models complex event interrelationships. FTA is a top down approach to deduct failure using Boolean logic. It uses symbols from electronics and logics fields. The main symbols used are the AND and the OR gate. Each of this has at least two inputs and a single output. The output of the AND gate occurs if only if all inputs occur. The output for the OR gate occurs if and only if at least one input occurs. The voting OR gate is also used; where the output occurs if and only if *k* or more of the input events occur. * Cause and effect diagrams: Typically after a brainstorming session the ideas are grouped into categories known as the six M’s. These are Methods, Manpower (personnel), Machines, Materials, Measurements and Mother Nature (environment). The diagram looks like a fishbone with the ideas written under each category. Data is then collected to verify which potential cause are actual contributors of variation.   Six Sigma looks for problems in the system that are causing variation by collecting data, using the data to make decisions on how to minimise the variation. Variation in product quality leads to scrap and rework, which are significant contributors to manufacturing overhead costs, delays in lead time, and product that does not meet customer requirements. There are several classes of tools to identify and understand variation. Graphic tools can be used to plot data over time exposing patterns of variation and relate process capability to customer specifications. Statistical analysis tools can also help to pinpoint differences in variation. Six Sigma uses a set of statistical tools (hypothesis testing, process capability, control charts, etc.) to make statistically sound decisions, determine when and when not to take action on the process and what type of action to take.  The sources of process variation can be divided into special and common causes. Common causes are those that are inherent to the process and generally cannot be controlled. This is a natural variation in the process. Examples can be temperature, electricity, machine wear, material, etc. Special causes are due to events that can be controlled easily and changed. Special causes can be due to unforeseen circumstances such as machine breakdown. If special causes are not dealt with in a systematic way adjusting for them might create more variation rather than less. This is sometimes called over-adjustment or over-control. On the other hand if the special cause is ignored, additional variation will be introduced to the process. This is referred to as under-adjustment. Process charts can be used to identify the presence of special causes so that appropriate action can be taken in a timely manner. | | | | | |
| Associated evidence | | | | | |
| I have used the DMAIC methodology and other methods of problem solving. An example is when after trimming a panel with a water jet machine, the panel came out of specification. The team decided to carry out a root cause analysis following a DMAIC methodology.  Define the problem: The CFRP small component was trimmed out of tolerance (undersized).  Measure (collect data): To validate the problem, the part was measured with a laser tracker. In various locations (on the machine, on a fixture, free-form).    Analyse: Data collected was analysed. It was found that the part was out of tolerances. A measurement error was discarded at this stage.  The RCA aim was to identify possible causal factors. The sequence of events that lead to the problem. The conditions that allowed the problem to occur. Identify other problems that surrounded the occurrence of the central problem. I used different tools for RCA.  A process flow was built to help identifying possible RC. Using this tool several mistakes were identified in the process chain.    Following the process map a brainstorming session took place. Using the process map a brainstorm or possible causes per process step was carried out. The output was a list of potential issues.    The brainstorm list was used to help populate a cause-and-effect diagram to further explore the problem.    Various issues were evident that could have contributed to the problem. We used 5 whys technique to drill down into the cause of the problem.   |  |  | | --- | --- | | Issue: Datum in fixture poorly machined.  Cause: Why? Drill broke during machining.  Cause: Why? Drill was blunt.  Cause: Why? Old drill used.  Cause: Why? No new drill available.  Cause: Why? Not ordered as start of project.  Cause: Why? No list of tools needed for project. | Issue: Datum raised 1.19 mm above part.  Cause: Why? To ensure clearance over raised edges.  Cause: Why? Part had extra material on edges.  Cause: Why? Due to manufacturing process. |   Improve: Recommend and implement solution. The identification of possible causes followed a plan for implementing solutions.    Control: Different control methods were set in place. In order to ensure that problems do not recur. For instance a Route Card checked by all team members was issued. A communication plan between the customer and teams was established. An FMEA which identified potential risked was carried out.    The effectiveness of the problem solving approach was confirmed as the implemented actions were successful for cutting the next set of components. Cutting a few more components also gave us the opportunity to discard proposed problem causes and identify the root cause. This was due to machine calibration and fixture design. | | | | | |

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| Index | 13.1 | Table | A.2 | Original index | 13.1 |
| Competency | | Practical problem solving (opportunity realisation). | | | |
| Performance criteria | | The ability to put forward potential solutions and select and verify the most appropriate. | | | |
| Understanding the competency | | Describes solution generation process used and how proposals address the root causes identified. Describes process used to establish the criteria for selection. Describes the verification process for the chosen solution(s). | | | |
| Applying the competency | | Demonstrates use of appropriate techniques to generate solution(s) to identify root cause(s), then sort, select and verify. | | | |
| Managing the competency | | Demonstration of review and check of solution generation and selection process. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| The ideas of causes of special variation can be gathered using different tools. The beliefs of what is causing the variation are theories that need to be tested. There are analytical tools for performing causal analysis and to find out which cause is contributing the most to the problem.  Scatter plots are causal analysis tools that help determine if a relationship exists between two data sets. Scatter plots help to find a visual correlation. Another tool for visualising correlations are Correlograms. For a statistical analytical tool, a correlation coefficient or regression analysis can be used to quantify the relationship between two or more factors. However they do not discover casual relationships.  A t-test is a statistical tool used to determine whether a significant difference exists between the means of two distributions or the mean of one distribution and a target value. It can be used, for example, to investigate if changes after implementing a new strategy had made a difference. A t-test follows the assumptions of normally distributed data with equal variances. Each sample is independent and there are no patterns or trends present; changing one data point should not change another.  Analysis of Variance (ANOVA) is used to determine if there are statistically significant differences in the mean in groups of continuous data. It is used to compare means of two or more sets of data and finds out if at least one set of data differs from the others. ANOVA follows the same assumptions as a t-test.  Regression Analysis is used to build a mathematical model that relates factors to output and quantifies the relationship. It finds out how the outcome will be affected by changing a unit of the inputs. The mathematical model formulated by regression analysis can be used to predict process performance resulting from any changes we make in the input variables.  Design of Experiments (DOE) is a systematic, rigorous approach to engineering problem-solving. It applies principles and techniques of data collection and statistics to ensure the validity of results. DOE is used to find cause-and-effect relationships by determining the relationship between factors affecting a process and the output of that process. DOE is used at various stages of continuous development. It is used as a process characterisation tool, process optimisation and robustness testing. The type of experimental design varies according to the DOE objective. | | | | | |
| Associated evidence | | | | | |
| I have used a systematic approach to problem solving, putting forward potential solutions and testing them according to a methodical plan. This has allowed me to demonstrate several Six Sigma tools. The problem under investigation was the supposed difference in surface condition of samples cut before and after a machine calibration. In order to assess this statement I carried out a t-test using data collected before and after the machine calibration. In this way the assumption of an effect after the machine calibration was tested and found true (as seen in the p-value < 0.05)    After confirming the assumption. The machine supplier was contacted and a list of potential causes was put together. Each one of them was investigated and scrutinised. For instance, we investigated a machine component (the mini hopper) that has a breathing valve and a motor. We cleaned and changed the breathing valve, carried out some cutting tests and compare the results with a t-test. The problem still persisted. Then we measured the frequency of the motor and tried to relate it to the frequency of the surface roughness inconsistencies, there was no correlation.    The next item under investigation was the high-pressure system. The machine supplier recommended looking at the pressure fluctuations and changing certain parts of the double intensifier pump.  After the changes in the high-pressure system, more test cuts were carried out to confirm that the change had a positive effect. It was found out that the surface roughness of the cuts matched those of our database. This supported the findings of the root cause of the problem being the high - | | | | | |

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| Index | 14 | Table | A.2/B.2 | Original index | 14/18 |
| Competency | | Presentation and reporting skills. | | | |
| Performance criteria | | The importance of communicating effectively to stakeholders through presentations and reports in order to drive the achievement of project objectives. | | | |
| Understanding the competency | | Describe effective ways to structure presentations and reports to meet required purposes with the expected audience. | | | |
| Applying the competency | | To have demonstrated the planning and delivery of presentations and reports to different audiences and measure effectiveness of these presentations and reports. | | | |
| Managing the competency | | To have measured the effectiveness of presentations and reports. | | | |
| Training the competency | | Delivery of training on presentation and reporting techniques. | | | |
| Competence statement | | | | | |
| Communication is a key factor in the success of any project. For a Six Sigma project to run smoothly (at least) the stakeholders need to understand the project background, objectives and plan. If people involved in the project are informed and taken into consideration for any decisions taken, the implementation phase will be facilitated. Because most of Six Sigma initiatives are strongly and directly endorsed by executive management, keeping them informed of the process and outcomes of the project will ensure their continued support and endorsement.  Successful Six Sigma projects will directly affect the stakeholders. Six Sigma projects will contribute to the business bottom line and will be of interest to financial executives which will want to know about the impact of the projects. Suppliers and customers may also want to know the impact of the projects. Suppliers will be intrigued about new business processes, customers will notice an improved of quality that needs to be communicated.  A communication plan is a good tool to ensure vital information related to the project is relayed to the stakeholders.  A communication plan is a good tool to ensure vital information related to the project is relayed to the stakeholders. The plan considers:   * What will be communicated: team meetings, meeting minutes, team work/action items, project status reports, project timeline, project reviews/tollgates, project success stories, storyboards, etc. * Who will do the communicating: project champion, Master Black Belt, Black Belt, Green Belt, quality analyst, Process Owner, team member, etc. * Why the communication will take place: establish and enforce a contract for communication. * Where will the communication take place: the physical or virtual location. * How will the communication happen: electronic mail, voice mail, conference call, video presentation, etc. * When the communication will take place: weekly, monthly, etc. * To whom the communication will be delivered: senior management, quality department, project champion, MBB, team members, etc. * Where the information will be stored: intranet, repositories, etc.   There are several tools and methods that can be used to communicate the project to different levels of stakeholders:   * Face-to-face: the most powerful leadership tool is personal communication. Direct interaction is the best way to listen and influence. * Formal presentations: using a presentation tool like PowerPoint, a formal presentation is common, effective, and repeatable leadership and communication tool. * Impromptu presentations: white boards and flip charts make ideal platforms for conveying important ideas and information, conducting brainstorming sessions, developing early designs and troubleshooting. * E-mails: messages, directives, requests and reports can all be communicated via e-mail, which communicates directly and by passing along through different audiences. Using attached files, e-mail is a powerful communication conduit. It disadvantages of been poor and inappropriate for resolving issues. * Shared repositories: systems like intranets, file servers, groupware, and enterprise application systems help communicate broadly and consistently. * Phone calls: particularly when there is an issue or problem, there is nothing quiet as effective as picking the phone and calling someone. * Memos and letters: formal memoranda and letters are most useful for communicating in an official manner, such as a policy directive or formal announcement.   The project is documented in a final project report which describes the project aims and objectives and how they were reached. The report can be organised according to the Six Sigma Define Measure Analyse Improve and Control phases, including an Executive Summary, an Introduction and Conclusions and Recommendations. The business case needs to be highlighted mentioning the cost-benefit of the project. A report / presentation is successful if it managed to communicate the story of the project, motivate people for further six sigma projects and if it is memorable. It should make an impression in the audience. | | | | | |
| Associated evidence | | | | | |
| Report writing and giving presentations is a vital part of my role as a researcher at the University of Sheffield, AMRC. The knowledge created through my research and engineering projects is often the product I present to the customers.  I have written multiple reports and given various presentations for a variety of audiences; ranging from scientific community, business people to students. The organisation and content of the reports and presentations varies according to the intended audience. For the scientific community (my Master’s and PhD theses, scientific articles), the organisation follows the IMRaD (Introduction, Methods, Results, and Discussion) structure. This type of structure facilitates reading and understanding of the research outcomes. However, I am aware of the drawback of the disparity between the flow of research and the sequence of the report. For business, high management people I tend to focus more on objectives and benefits of the research. I usually present a higher level document stressing more results, advantages, disadvantages and future plans. When dealing with students, I try the presentations and reports to be more engaging. I present more analogies and practical examples.  Examples of presentations I have given:   * International Conferences: International Water Jetting Conference, Advances in Abrasive Technology, International Academy for Production Engineering (CIRP). * AMRC stakeholders: AMRC Technical Fellows Conference. * Project kickoff meetings: EU-funded projects, AMRC specific/generic projects. * Project closure meetings: EU-funded projects, AMRC specific/generic projects. * Teaching: AMRC delegates. * Workshops: Non-conventional machining. * Community of Practise meetings.   Examples of reports I have written:   * Bachelors, Masters and PhD theses. * Scientific articles in Journals and Conference proceedings. * Project reports.   A way of measuring effectiveness of presentations and reports can be based on different metrics, according to the objective of the presentation or report. For instance, if the presentation was aimed to obtaining funding or projects, the success can be measured if the outcome was successful at generating funding projects. I had that success when giving a presentation at the AMRC Tech Fellow’s meeting. I aimed the presentation at expanding the industrialist ideas on the use of Water Jet technology. As a result I got a project using Water Jet to clean metal sheets prior to a secondary process. A way to measure success when presenting to students is by asking them to complete a questionnaire at the end of the session. If students reply to the questions with high successful rate, then the objective was achieved. Metrics for scientific articles are the impact factor or number of reads    I have provided training to my research assistant and research student in report writing and giving presentations. I authorise reports and presentations before they are issued to stakeholders. | | | | | |

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| Index | 15 | Table | A.2 | Original index | 15 |
| Competency | | Process thinking skills | | | |
| Performance criteria | | The need to define the scope and ownership of a process. Planning and managing available resources and process activity in support of objectives using measurement to achieve outcomes. | | | |
| Understanding the competency | | To describe the processes and/or systems in which the Black Belt and/or Black Belt project operates. To describe what constitutes good process management skills. | | | |
| Applying the competency | | Evidence of using process thinking techniques such as SIPOC. | | | |
| Managing the competency | | Evidence of reviewing use of process analysis techniques. To describe how skills gaps in process management may impact process performance. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| A process is a series of steps and decisions taken in order to achieve a particular end, considering variability of the time each step takes, the timing of the steps, their interdependence and the assignment or resources. Processes are often broken down into smaller processes, sub-processes. A process has boundaries; it has a start and an end point. Processes have inputs as well as outputs. The inputs of a process can be classified using the 6M acronym: material, man, machine, method, Mother Nature, management and measurement systems.  A process owner is a person with the authority to make changes in the process. She/he coordinates the various functions and work activities at all levels of a process and manages the entire process cycle so as to ensure performance effectiveness.  The skills that a process manager requires to be successful can be classed into transformational (building a business case and vision, project management, knowledge of organisational structure, communication, organizational change techniques), operational (process discovery, process modelling, process governance, process performance management, constructing a process model methodology toolbox) and technical (solution architecture and design, process model technology product knowledge, process optimisation).  Good process management uses a holistic approach focusing on the organisation as a whole. The processes that may add to the effectiveness and efficiency of the business as a whole need to be identified. This could be achieved by modelling the process chain.  A way of modelling a process is by a flowchart or process map. A process map offers a visual display of the process steps from start to finish showing their interdependence, time, decision points, options, inputs and outputs. It can serve as an instruction manual or a tool for facilitating detailed analysis for streamlining the process. Process maps can be built by hand or specialised software (e.g. R has the functionality for this). Process maps can contain additional information about the steps including costs, setup time, cycle time, inventory, types of defects that can occur, probability of defects and other appropriate information.  A SIPOC is a tool used to map processes at a higher level. It aids recognising the;   * Suppliers: internal or external providers of resources, materials, knowledge and services that the process requires. * Inputs: elements outside the process boundaries that feed the process so the outputs can be produced. * Outputs: the final end product or services produced by the process. * Process: the sequence of steps required to produce the output * Customers: people who receive the intermediate or final outputs of the process steps.   There are different metrics that can be considered for analysing processes.   * Work in progress (WIP): is the material that has been input to the process but that has not reached the output stage. This includes the material waiting to be processed by one or more steps. The longer the WIP the more time needed to complete the work orders. * Work in queue (WIQ): is the material waiting to be processed by some step in the process and is one component of WIP. This is an indication of a bottle neck step. * Touch time / value added time: is the time that material is actually being processed by one of the steps and value is added. This is typically only a small proportion of the total production time. * Cycle time: is the average time for a particular step to complete one item. * Takt time: is the time interval between consecutive items in a production system that must be achieved to meet customer demand. The takt time is computed as takt time = time available / number of units to be produced. * Process lead time: how long the process takes from start to end. Sometimes it is estimated comparing the work in process (WIP) with the number of completions per day. Lead time = WIP/completions. * Cycle Efficiency: a relationship between the value-added time and total lead time. Calculated as Process cycle efficiency = value-added time / total lead time. * Process cycle efficiency: determined by comparing the value-added time (work that a customer would consider as necessary to create a product or service) with the total lead time. Process Cycle Efficiency = Value-Added Time / Total Lead Time. * Throughput: is the number of items or amount of material output from the process in a given period of time. * Setup time / change-over time: is the time required to convert from producing one product to producing a different one on a particular process step.   Gap analysis is a tool used to identify performance difference between different states. It is often used to benchmark and is used at different levels:   * Business: perform a comparison with competitors. * Process: comparison between old process and new, customer requirements and current process. GAP analysis can be used to monitor various processes and systems such as market conditions, competitor actions, and internal organisation performance. GAP analysis can be used to compare averages, histograms, complex regression analysis, or process control charts for example. * Product: comparison between different features of products versus critical-to-X perspectives or voice-of-customer. | | | | | |
| Associated evidence | | | | | |
| Six Sigma projects affect processes directly as they look to optimise them using a systematic approach where first a benchmark of the process is carried out using various tools such as process maps, SIPOC, other diagrams as PETRI Nets, Spaghetti or even computer simulation tools.  I have used various process model tools such as SIPOC which facilitated the understanding of the process of water jetting bearing cages by listing the suppliers, inputs, outputs and customers. It also provided a high level flowchart of the process and decomposed the sub-process of set-up.    From the SIPOC and high level process chart several metrics that allowed to benchmark the process before an improvement project was carried out:   * Touch time: cut pockets = 90 seconds x 57 pockets = 85.5 minutes * Cycle time: inspect and debur (30 mins) + setup (120 minutes) + test/inspect (90 minutes) + cut pockets (85.5 minutes) + inspect (120 minutes) + pack (30 minutes) = 475.5 minutes ~ 8 hours * Tak time with a demand of 7 per 35 hour week = 35 / 5 = 7 hours / cage * Cycle Efficiency = 85.5/475.5 = 0.21   After the process benchmark is completed, a Six Sigma project to streamline the process can be carried out. In this case, I decided to focus on set-up time and reducing process time. This lead to a new set-up process.    The various process metrics are useful in order to study and understand where improvements can be gained. Carrying out a Gap Analysis between the old process and the improve process, leads to a cycle time of under 7 hours which satisfies the Tak time of 7 hours per cage, to satisfy customer demand. This comes with an Cycle Efficiency of 0.15. resulting from reducing touch time.   * Touch time: cut pockets = 60 seconds x 57 pockets = 57 minutes * Cycle time: inspect and debur (30 mins) + setup (45 minutes) + test/inspect (90 minutes) + cut pockets (57 minutes) + inspect (120 minutes) + pack (30 minutes) = 372 minutes ~ 6.2 hours * Tak time with a demand of 7 per 35 hour week = 35 / 5 = 7 hours / cage * Cycle Efficiency = 57/372 = 0.15   A good process manager requires competency in:   * Aligning processes with business strategy: Processes have to be tailored to the business strategy. Hence, an understanding of the ways a firm achieves its vision, the priority of the objectives and how they fit in their business model is important. * Modelling processes: is a core skill for process manager. This could be achieved at different levels, from simple pictorial diagrams to building computarised models with specialist software such as Bonita, Open ModelSphere, ARIS Express, etc * Measuring processes: an important part of process management. Identification of suitable metrics according to various processes and business strategy. * Analysing and benchmarking processes: in order to identify areas of improvement and to carry out gap analysis. * Harvesting Policies and Rules: processes exist within a wider system. Processes are affected by policies and rules (e.g. Health and Safety, working patterns, etc.). The identification of such policies and rules is important if a process is to be understood. * Improving processes: the ability to manipulate tasks and procedures in order to enhance the process. Many times processes are altered just to find it a better performance was obtained before changes were implemented. Also it is important to understand how changes in one variable affect other output. * Managing the changing of a culture: optimising processes requires change. A good process manager has to be able to excel in change management. * Governance (decision making): process managers should be aware that the decisions that they make can really make an impact (positive or negative) in the company’s bottom line. * Deploying Technology: once processes have been optimised, streamlined in a pilot run, the changes need to be deployed. This might involve the adoption of new technology | | | | | |

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| Index | 16 | Table | A.2 | Original index | 16 |
| Competency | | Project management. | | | |
| Performance criteria | | Managing a finite time improvement activity with a defined group of people. Coordinating their activities to meet the phase and overall requirements. | | | |
| Understanding the competency | | Describes what constitutes good project management skills. | | | |
| Applying the competency | | To have demonstrated the effective management of a Six Sigma project. | | | |
| Managing the competency | | To have reviewed and managed delivery of key project metrics such as time cost and resource. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| To be a successful Six Sigma Manager it is not only necessary to understand the Six Sigma methods and tools but also to have management skills. An array of different Six Sigma projects may happen simultaneously. Projects can be long or short, within a single department or multi-department, within the organisation or outside, etc.  Project management is the application of processes, methods, knowledge, skills and experience to achieve the project objectives. The skills and tool required to manage a Six Sigma project are similar to those required to manage other types of projects, following standard project management rules and guidelines. There are a variety of Project Management methodologies such as PRINCE2.  Managing a project starts with the definition of objectives and results that are sought. These are documented in a project charter. The project charter, an outcome of the define phase, is an informal contract that documents the project’s:   * Goals and objectives: Project statement explaining how the project will impact the company. The SMART mnemonic can be used to help the setting of objectives. Objectives should be Specific (target a specific area for improvement), Measurable (quantify or at least suggest an indicator of progress), Assignable (specify who will do it), Realistic (state what results can realistically be achieved), and Time-related (specify when the results can be achieved). * Benefits: how the company will be better if the project is successful. * Scope: what is included and not included in the project. There are various tools that can be used to set the scope of the project for example: cascade method (y = f(x)), Pareto Charts, cause-and-effect diagrams, affinity diagrams (show the linkages between the project and other projects or processes), process maps. The scope of the project may be defined or limited by factors such as geography, demographics, organisation structure, process boundaries, relationships (e.g. suppliers, customers, contract personnel, etc.). Care should be taken to ensure the scope of the project is not too wide. Projects can be subdivided into a series of smaller projects that can be managed in a shorter period of time by a small project team. * Expected results: Project metrics for quantifying project success should be in place. Such metrics could be financial or non-financial. Project metrics selected should reflect the VoC, they should be connected to key business metrics and might not be the ones currently in used. Metrics could be divided into financial (cost per unit, inventory levels, cost of poor quality), customer (satisfaction, on-time delivery, final product quality), internal business processes (defects, inspection data, DPMO, sigma level, cycle time, rework hours), employee learning and Growth (six sigma tool utilisation, quality training, lessons learnt).   A means of tracking project progress is required and usually expressed in the project plan. A progress towards objectives measurement criteria should be established. This could be in terms of time (activities completed), objective oriented (goals achieved) or financial (money spent). There are several tools that can assist with project tracking.   * Gantt chart: is a type of bar chart that illustrates the progress of a project. Gant Charts show the start, finish dates, resources, cost and interdependence of project tasks. * PERT chart: is used to schedule, organise and coordinate tasks within a project. PERT stand for Programme Evaluation Review Technique. It represents a project as a network diagram consisting of nodes representing events, or milestones in the project linked by vectors representing tasks in the project. The direction of arrows on the lines indicates the sequence of the tasks. The Earliest start time (ET) and Latest start Time (LT) is often indicated in the chart. * Critical Path Analysis: is an algorithm for calculating the longest sequence of activities in a project plan. It is often used in conjunction with a PERT Chart. It uses the information on the chart to identify a “critical path”. An activity on the critical path cannot be started until its predecessor’s activity is complete. If it is delayed the entire project will be delated. Activities not on the critical path will have some slack time (LT-ET). * Story boards: is a visual way of showing an overview, progress and success of a project. It can highlight changes that have been made due to the project, providing snapshots comparing the “before” and “after” the project. Story boards can be formatted according to the five sections of Six Sigma projects (DMAIC).   Six Sigma Black Belts should also manage all documentation created within the project. There will be a variety of data-driven and fact-driven project documentation that needs control via Project Configuration Management (PCM). PCM addresses the composition of a project, the documentation defining it and other data supporting it. PCM acts as a version control ensuring that the deliverable meets the specified performance criteria.  Project management is also concerned with team leadership. A Six Sigma Black Belt practitioner should be familiar with team working, setting goals, commitments and ground rules within teams. Knowledge of selecting teams according to skills is also necessary. For a successful group to be formed managing the team stages (forming, storming, norming, performing and adjourning) needs to be facilitated. Group dynamic challenges such as overbearing / dominant and reluctant participants, feuding and other forms of unproductive disagreement, unquestioned acceptance of opinions as facts, groupthink, floundering, rushing to accomplish or finish, digression, tangents, etc. through coaching, mentoring and intervention should be overcome. Black belts should also be familiar with team-building techniques, team facilitation techniques and team performance evaluation.  Project management in Six Sigma projects is also concerned with Change Management. Often when Six Sigma projects are run, the output is a change. This change can have impact in processes, systems, organisational structure or job roles. Organisations tend to resist to change and solutions difficult to implement. Change management is the process, tools and techniques to manage the people side of change to achieve the required business outcome. Change management incorporates the organisational tools that can be utilised to help individuals make successful personal transition resulting in the adoption and realisation of change. Project management and change management support the transition from a current state to a desired one. Project management focuses on the tasks to achieve project requirements while change management focuses on the people impacted by the change. | | | | | |
| Associated evidence | | | | | |
| I am an experienced project manager. I have managed my “Green Belt” project where I looked at streamlining the flow of work orders in my research group. I am currently managing my “Black Belt” project where I am looking at Gender Diversity at the AMRC. Apart from Six Sigma projects, I have managed an array of research and industrial projects. I am in charge of creating all documentation (Project Charter, Risk Management Plan, Configuration Management Plan, Communication Plan, Gantt Chart, etc.). and following through from project conception to closure.    I manage projects according to AMRC’s quality control system, which is similar to PRINCE2 methodology, in which projects are divided by stages. Each stage has a gate where milestones are achieved and discussed. This approach provides the opportunity to revise project metrics such as time, cost and resource utilisation. A risk register is carried forward and revised. A Gant Chart is updated regularly, and project cost and resources revised. If needed corrective actions are set up in order to bring the project back into schedule, should any unplanned issues arise. The project finishes with a closing meeting where lessons learnt are discussed and documented. In this way, I have reviewed, managed and deliver projects according to time, cost and resource utilisation. | | | | | |

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| Index | 17 | Table | A.2/B.2 | Original index | 17/11 |
| Competency | | Risk analysis and management. | | | |
| Performance criteria | | To understand the concept of risk and how to manage it in relationship to a Six Sigma or Lean project. | | | |
| Understanding the competency | | Describes what is meant by risk and how risks are evaluated and prioritised. Explains how risks should be proactively managed in pursuit of project and lean objectives. | | | |
| Applying the competency | | To have demonstrated identification of risk. To have demonstrated how to quantify and prioritise risk, e.g. through use of FMEA, in process change. | | | |
| Managing the competency | | To have demonstrated how risk has been managed. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| A risk is an uncertain event or set of events that, should it occur, will have an effect on the achievement of objectives. Uncertainty may arise from events inside or outside the organisation. Risks result from uncertainty in the different aspects that may have an effect on the project such as economy, health and safety, natural disasters, project failure, etc. Risks can have a negative or positive impact on objectives. They can be differentiated as threats (uncertain events that would have a negative impact in objectives) and opportunities (uncertain events that would have a positive impact in objectives).  Risk management is the systematic application of principles, approaches and processes to the tasks of identifying and assessing risks, planning and implementing risk responses and communicating risk management activities with stakeholders.  Risk management consists of a series of steps:   1. Risk identification: is the process of determining sources that could have an effect on the project, potentially preventing it from achieving its objectives. Risks may come from internal or external sources. Risk identification includes documenting and communicating the issue. Risks can be expressed as cause, event and effect. There are several techniques that can be used for risk identification:  * SWOT Analysis (Strength, Weakness, Opportunities and Threats): it is a useful tool for identifying internal and external factors that can affect in a positive or negative way by dividing them into four categories. Strengths are factors that provide an advantage, areas of competency, resources, uniqueness. Weaknesses are factors that provide a disadvantage, things that can be improved, lack of competency. Opportunities are factors that could be exploited to gain an advantage, changes in technology, government policy, market trends, financial markets, etc. Threats are factors that could have a negative effect on the project, obstacles, changes, etc. * PEST Analysis: it is similar to SWOT but considers four environmental scanning perspectives. Political aspect looks for stability, threats of wars, regulatory issues, tax considerations, labour problems, law, and so forth. Economic aspect looks at exchange rates, market conditions, unemployment rates, inflation factors, interest rates, etc. Social looks at factors such as education considerations, demographics, health factors, cultural implications, etc. Technological looks at developments of new technology, rate of technological change, cost impact of technology and so forth. There are other variants of PEST such as PESTLE adding Legal and Environmental factors. SLEPT which adds Legal. STEPE adding ecological factors; and more. * Assumption analysis: minimises the risks involved in making assumptions during the process of planning a particular project. The assumptions that are being made during the project planning are documented. The risks that exists based on these assumptions is then identified. If the assumption causes an extreme risk alternative courses of action are sought. * Delphi Technique: is a method used to estimate the likelihood and outcome of future events. The method entails a group of experts who anonymously reply to questionnaires and subsequently receive feedback in the form of a statistical representation of the group response, and then the process is repeated. The Delphi method seeks to reach the correct response through consensus. * Lessons learnt risks checklists and brainstorming.  1. Risk Assessment: provides qualitative and quantitative methods to determine how likely a potential risk is and how will it impacts the project across a variety of metrics. Metrics may include cost, schedule, technical performance, as well as capability or functionality impact. Evaluate or rank the risk: by determining the risk magnitude. Examples of risk estimation techniques:    * Probability impact grid: contains ranking values that may be used to rank threats and opportunities qualitatively. The probability scales are measured of probability derived from percentages, and the impact scales are selected to reflect the level of impact on project objectives. The values within the grid cells are the combination of a particular probability and impact, and are determined by multiplying the probability by the impact. In this way sources of highest risk can be identified. An example is given in  * Expected Value: quantifies risk by combining the cost of the risk impact with the probability of the risk occurring. Expected value is useful to provide a score to prioritise risks. * Probability trees: graphical representations of possible events resulting from given circumstances. A probability tree can be used to predict an outcome in a qualitative way when historical data is used to populate the likelihood of each circumstance happening. Probability trees assist in communicating to project participants or decision makers the likelihood of the different possible outcomes to a set of circumstances. * Pareto Analysis: Ranks or orders risks to determine the order in which they should be addressed.   An evaluation of the risk is also necessary in order to assess if the risk exposure remains within the risk appetite determined by the organisation. Techniques to evaluate risk are:   * Risk models: such as Monte Carlo simulation enable “what if” scenarios to be run using random numbers to determine whether each risk within a given range occurs. The simulations are repeatedly run to predict the average level of risk to the project’s timescale or cost. * Expected monetary value: assesses the economic risk of a project. The expected value is defined as the difference between expected profits and expected costs. Expected profit is the probability of receiving a certain profit times the profit, and expected cost is the probability that a certain costs will be incurred times the cost. Estimation of probabilities can be subjective and often a worst case and best case scenarios are built.  1. Risk planning: assess the highest ranked risks and set out a plan to treat or modify these risks to achieve acceptable risk levels. Create a risk mitigation strategy, preventive plans and contingency plans. Owners and actionees need to be identified and agreed. 2. Monitor and review the risk.   Risks are maintained in a risk register which records identified risks and decisions relating to their analysis, management and review. It provides the status and history of the development of risks. A risk register should be created at the Define stage of a Six Sigma project. Communication should be undertaken continually ensuring information related to the threats and opportunities faced by the project is communicated to all stakeholders. | | | | | |
| Associated evidence | | | | | |
| For each project that I manage, including Six Sigma initiatives, I carry out a full risk assessment. An example is for my current Black Belt project where I am looking at benchmarking and improving the Gender and Diversity at the AMRC.   1. Risk Identification: I carried out a SWOT analysis to identify the Strengths, Weaknesses, Opportunities and Threats.      1. Risk assessment: The AMRC method is that of an impact grid. The potential risks gathered by techniques such as brainstorming and SWOT analysis are documented into this template, providing a description of the event, description of the Impact, the probability of the event happening and the Impact of the risk in the project. The impact can be in certain project categories such as: Data collection, Environmental, Equipment, H&S, Materials, Personnel and so on.      1. Risk planning: The AMRC Risk Assessment Document automatically provides a Ranking to the risks. In this way, the highest risks can be identified. A “risk owner” is identified who will be in charge of managing the risks throughout the project. Mitigation actions are proposed and the risk impact re-calculated. Actions are identified. 2. Monitor and review risk: The risks are monitored every meeting by looking at the Risk Assessment Document and following actions. New risks can be identified at any stage.   An example of a demonstration of managing risk is the prompt identification of a risk associated to the water jet machine. The operator had to step on the machine tank in order to set-up and inspect a part that was being machined. This caused a risk on the operator to fall inside the tank and hurt himself. The risk was identified and as a mitigation action a platform was suggested. A movable platform was built and used by the operator to step inside the machine, allowing him to carry out his job safetly. | | | | | |

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| Index | 18 | Table | A.2/B.2 | Original index | 18/16 |
| Competency | | Self-review and development | | | |
| Performance criteria | | To be able to understand own strengths and areas requiring development. | | | |
| Understanding the competency | | To describe own strengths and plans for self-development. | | | |
| Applying the competency | | To have demonstrated self-review and suitable action taken. | | | |
| Managing the competency | |  | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Personal development involves activities to gain and improve skills that will help at a professional or personal level. Concentrating on further developing our strengths has the advantage of being able to become an expert and excel at a particular issue. Acquiring new skills or try to develop something we are not good at has the risk of not being able to be exceptionally good at it.  Strengths are the things that people are good at. They refer to people’s character. Often strengths can be a weakness and vice versa. Strengths can be demonstrated. For example if you are good at swimming you will be able to swim across a swimming pool without drowning. We can divide the strengths into three layers:   1. Skills: These can be taught by demonstration and improved through repetition. Examples of skills are:  |  |  | | --- | --- | | * Public speaking | * Trade maths | | * Writing | * Online search | | * Time-management | * Data Analysis | | * Networking | * Conflict resolution | | * Decision making | * Self-motivation | | * Graphic Design | * Foreign Languages |  1. Behaviours: The way in which one acts or conducts oneself. They influence the way we learn and apply skills. Examples of behaviours are:  |  |  | | --- | --- | | * Considerate | * Open to feedback | | * Demonstrate compassion | * Adaptable and flexible | | * Empathy | * Resilient | | * Stable and consistent | * Aggressive | | * Cooperative | * Bossy | | * Caring | * Deceitful | | * Faithfull | * Polite | | * Excitable | * Pleasant |  1. Beliefs, values and attitude: A belief is an internal feeling that something is true, even though that belief may be unproven or irrational. A value is a measure of the worth or importance a person attaches to something. An attitude is the way a person expresses or applies their beliefs and values, and is expressed through words and behaviour.   Beliefs and attitudes set boundaries within which behaviours support the development of skills. Here are some examples of beliefs and values:   |  |  | | --- | --- | | * Belief that everything will turn out all right. | * Belief that family is of fundamental importance | | * Belief that people always want to do a good job. | * Belief that honesty is always the best policy and trust has to be earned. | | * Belief that life is a journey not a destination. | * Belief in maintaining a healthy work/life balance | | * Belief, or lack thereof, in God | * A commitment to sustainability and acting in an environmentally friendly way. | | * Belief that knowledge is fixed (one way to approach a problem) | * A commitment to innovation and excellence | | * Belief that we are in control of our life | * A commitment to building strong communities. | | | | | | |
| Associated evidence | | | | | |
| To understand my own strengths entails identifying what I am good at; the skills that I master, the behaviours that influence me and the attitudes and beliefs that characterise me. The first step is to analyse the skills by creating a skills inventory. Identifying 5 to 10 skills that I currently have. Thinking about what people ask for my help, what others complimented me about, what projects have been easy, what hobbies I have, etc. Talking to people that know me helped populating the list of skills.  The second step is to understand the most and least useful of my behaviours. The behavioural strengths are the things that facilitate applying the skills to a greater effect. Including a column on the list of skills writing down the behaviours that help me applying these skills to Black Belt. In a second column I wrote the behaviours that hinder me, that stop me from getting the best outcomes from applying my skills. I looked for themes in the enhancing behaviours, these are my signature strengths. They are behaviours that come naturally to me that serve to enhance the impact of my skills.  The third dimension to identify is beliefs and attitudes. Beliefs that reinforce the values and ability are useful and are considered strengths. Beliefs and attitudes that undermine our values and detract from our sense of capability are weaknesses.  List of skills I have, relationship to Black Belt and behaviours that help / hinder my performance.   |  |  |  |  | | --- | --- | --- | --- | | **Skills** | **Relationship to role and Black Belt** | **Behaviours that help apply skills** | **Behaviours that hinder my progress** | | Public speaking / Presentation skills | Presenting project outcomes. | Enthusiastic, excitable, creative | Nervousness | | Data Analysis / Practical problem solving | Statistical analysis. Problem solving.  Data collection | Attention to detail, challenge driven, goal driven, practical. | Have to have a second opinion, doubt in myself. | | Statistical software / Statistics / Six Sigma tools / Numeracy | Statistics, probability, process capability, hypothesis testing. DOE, process control. | Analytical, logical, creative | Frustrated if cannot understand. | | Networking | Change management. Listening to VoC. Team formation. | Social, interactive, approachable, friendly, trustworthy | Nervousness, shy, introvert | | Training / Coaching | Getting people involved in continuous improvement project. Change management. Team performance evaluation. | Considerate, polite, empathetic, professional. | Defensive, not open to feedback. | | Project management | Project planning. | Punctual, hard-working, resourceful | Belief that everything will be okay. Attention to detail. | | Self-motivation | Team management. Leadership | Excitable, dedicated, independent | Depressed after failure, get bored if task is trivial. | | Result driven | Improve systems, statistics | Analytical, logical, creative | Frustrated if results are not good | | Process management | Process improvement | Understanding of mechanics | Belief that things follow common sense | | Motivational skills | Team work, leadership | Social, interactive, approachable | Nervousness, shy, introvert | | Computer literacy | Statistical software, report writing, presentations | Analytical, creative | Belief that I have to be proficient at everything. | | Business perception | Metrics, project selection. | Interest in finances. | People focus | | Customer focus | Capture voice of the costumer, Business metrics | People focus, social, interactive | Nervousness, shy, introvert | | Interpersonal skills | Team work, presenting outcomes | Social, interactive, approachable | Nervousness, shy, introvert |   Personality tests can also help understand my strengths and weaknesses. There are few tests available online for free such as [DISC Personality Testing](https://discpersonalitytesting.com/free-disc-test/), [Strength Tests](http://richardstep.com/richardstep-strengths-weaknesses-aptitude-test/free-aptitude-test-find-your-strengths-weaknesses-online-version/) and [how to fascinate](http://www.howtofascinate.com/get-my-profile).  Personality tests results        Personal development plan  I plan to obtain three certifications: PRINCE2, Black-Belt and CEng. The PRINCE2 qualification will validate and enhance my existing knowledge of project management. Black-Belt will allow me to be involved in more continuous improvement projects and directly applied the knowledge acquired to the workshop. CEng with validate my engineering knowledge.  To improve my research profile by writing at least three high-profile research articles. I plan to form a stronger team of non-conventional machining by bringing new partners to the AMRC. I will look for commercial work, with views of rolling out the technology developed within my group through a spin-off company.  Within the next 2 – 5 years I plan to obtain a MBA, which I am currently enrolled in.  Doing this course will provide the necessary tools for pursuing a more managerial position such as Technology Transfer Officer or set up a spin-off company or my own business. | | | | | |

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| Index | 19 | Table | A.2 | Original index | 19 |
| Competency | | Six Sigma tools. | | | |
| Performance criteria | | To understand the application of Six Sigma tools and techniques (refer to ISO 13053-2). | | | |
| Understanding the competency | | Describes the use and application of these techniques. | | | |
| Applying the competency | | To have demonstrated the correct selection and application of appropriate Six Sigma tools and techniques in previous projects. | | | |
| Managing the competency | | To review the use of suitable techniques. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| A Six Sigma project is usually executed by the DMAIC (define, measure, analyse, improve and control) methodology. The phases of the methodology are followed in sequence. However, once data have been gathered and analysed, the project is reviewed and if necessary the first three steps revisited. The project is usually continued until the project definition agrees with the information derived from the data. Regular reviews are held and reports are submitted to the Project Sponsor(s) at all phases.    The purpose of the define phase is to delimit the project. The outputs of the define phase include:   * A project charter including risk analysis * Six Sigma indicators * SIPOC diagrams * Flowcharts * Pareto diagrams * A list of Critical To Quality Characteristics (CTQC) * Financial result costing (profit estimation); and * Project review   The purpose of the measure phase is to develop a data collection plan, to collect the data, to evaluate the data, and to create a baseline of recent process performance. Outputs include:   * Measurement system analysis * Data collection plan * Sample size determination * DPMO * Probability distribution tests * Trend charts * Control charts * Histograms * Capability and/or performance analyses of affected processes and * Project review   The purpose of the analyse phase is to identify the gaps between baseline performance and targets, to understand the root source of variation and prioritise improvement opportunities. Outputs of this phase include:   * Cause and effect diagrams * Process FMEA * FTA * 5-why analyses * Sample size determination * Probability distribution tests * Hypothesis tests * ANOVA * Regression and correlation analyses * DOEs * A list of significant KPVIs * Value/non value add analysis / waste identification and * Project review   The purpose of the improve phase is to establish a robust improvement to the process. Outputs of this phase include:   * Solution selection matrix * Mistake proofing * Sample size determination * Response surface DOEs * Parameter design DOEs * Updated process FMEAs * Initial process studies’ capability and/or performance indices * Process map of what the process should now be * An updated list of CTQCs * Six Sigma indicators * Project review   The purpose of the control phase is to maintain the changes and new performance of the process. Outputs of this phase are:   * Process control plans * Updated list of CTQC * Further MSA * Control charts * On-going capability * 5s * TPM * Financial costing (actual vs expected) * Summary, project review, generic benefits analysis | | | | | |
| Associated evidence | | | | | |
| I have used the following Six Sigma tools in my projects   |  |  | | --- | --- | | **Tool** | **Use** | | Capability /performance | I have carried out a process capability assessment of a waterjet machine for cutting composite material | | Descriptive statistics | I have carried multiple descriptive statistics of data sets, prior to carrying out an exploratory analysis. | | Financial justification | I have assessed financial justification with Return of Investment | | Gantt Chart | I have used Gantt charts as a way to track time, resources and cost of projects. | | Non-conformance opportunities identification | I have identified non-conformance by means of raising quality “flags” | | Prioritisation matrix | I have used prioritisation matrix for project selection. | | Process flow chart | I have used process flow chart to depict the process steps. | | Project charter | I have used process charter to define projects, set scope, cost and time frame. | | Project review | I have carried out project review meetings. | | Project risk analysis | I have done project risk assessments. | | RACI matrix | I have used RACI matrix when working with teams in a project | | Benchmarking | Used for understanding the before and after of a project or comparing different systems. | | Data collection plan | Used to define strategies for handling and collecting data | | Measurement system analysis | Used to understand measuring systems and measuring system selection. | | Probability distribution (normality) tests | Used as part of exploratory analysis to assess normality of data (Shapiro-Wilk test, or Smirnof) | | Sample size determination | Used when designing experiments or carrying out a statistical analysis. | | ANOVA | I have used ANOVA for identifying differences in options. | | C&E diagram | I have used cause and effect diagrams for identifying production problems. | | DOE | Extensively used for characterising and optimising processes. | | Hypothesis testing | Used extensively for analysing two options | | Process FMEA | Used for risk assessment and for analysing problems | | Regression and correlation | Used extensively for characterising processes, prediction and optimisation. | | 5-why analysis | Used for problem solving, getting to the root of the problem. | | Brainstorming | Used extensively for generating ideas for problem solving. | | 5S | Used at the workshop for organising work space | | Control plan | Used to maintain improvements. | | | | | | |

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| Competency | | Stakeholder management | | | |
| Performance criteria | | To have knowledge of stakeholder management techniques in pursuit of operational goals. | | | |
| Understanding the competency | | Describes types of stakeholder and appropriate techniques for stakeholder management. | | | |
| Applying the competency | | To have demonstrated proactive and continual assessment of stakeholder’s status in pursuit of operational goals. | | | |
| Managing the competency | | Demonstration of continuous stakeholder management and monitoring using appropriate techniques. | | | |
| Training the competency | | Demonstration of training sessions on stakeholder’s management techniques and methods. | | | |
| Competence statement | | | | | |
| Stakeholders are people, departments, groups that have an investment, interest or concern in the success or actions taken by an organisation. Stakeholders can affect or be affected by the organisation’s actions, objectives and policies. In a Six Sigma project stakeholders are anyone associated with the project either directly or indirectly, for example: supervisors, team members, department heads, process owners, directors, suppliers, etc.  Stakeholder management is a critical component to the successful delivery of any project, programme or activity. The aim is to provide decision makers with information about the individuals and groups that may affect the achievement or otherwise of goals. This makes it easier to anticipate problems, gain the support of the most influential stakeholders. Stakeholders management:   * Prevents teams from not considering people that are key to project’s success * Ensures all stakeholders understand the process and the benefits of the project * Helps gain commitment for the project by identifying the correct influencing and communication strategy * Helps build into the plan the actions that will win people’s support by anticipating their reaction to the project * Helps clarify priority objectives and initiatives to better manage motivation   Stage holder management involves various steps:  1. Identifying stakeholder groups  Stakeholders can be classified into different groups:   * Internal: belong to the organisation such as employees, managers, trade union members, departments. * Interface stakeholders: are those who function both internally and externally in relation to the organisation, for instance the board of directors, medical staff. * External: are not part of the organisation and fall into three categories:   + Those who provide inputs to the organisation such as suppliers   + Those who compete with the organisation   + Those with a special interest in how the organisation functions e.g. government, regulators * Primary: define the business and are vital to its continued existence; for example customers, suppliers, employees, shareholders, investors, community. * Secondary: are those who may affect relationships with primary stakeholders. Examples are: business partners, competitors, inspectors and regulators, consumer groups, government, media.   One way of identify, visualising and analysing stakeholders relationships is the Stakeholder Onion Diagram. In this diagram the project goal is placed at the centre of the onion. The diagram is usually made up of four to five layers that represent:   * The product or project * The business system * The business * The environment * Other stakeholders   Other techniques for stakeholder identification such as creating a list by looking at the SIPOC (supplier, input, process, output, customer) or brainstorming could be used.  2. Prioritising stakeholders  Prioritising stakeholders according to the level of interest they have in the project and the power to affect or be affected by it will help in deciding where the managing effort should be invested. A higher level of engagement should be devoted to stakeholders with high interest and high power, high power stakeholders with little interest should be kept satisfied, but not overwhelmed with too much information. Stakeholders with high interest but little power should be kept informed. A stakeholder power/interest matrix helps visualise this.  3. Defining how each stakeholder is positively and/or negatively impacted  Determining and documenting how each stakeholder is affected by the project. It is useful to make a table with the stakeholder name/role and the impact e.g. “will benefit from cost saving”, “will benefit from reduced physical work”, etc.  4. Determining stakeholder’s current attitude  Determining what support is necessary from the stakeholder to ensure the project’s success and what their current attitude is regarding the project. A technique that can be useful is to rank from one to five where on is the “stakeholder is an opponent” and five is “stakeholder is very supportive”.  5. Developing a communication plan (influence strategy)  Making a comparison between stakeholder’s attitude towards the project and the ideal to understand the gap. Developing a communication strategy to close the gap. Considering what needs to be communicated, how to communicate and when. Based on the influence power of a specific stakeholder and the importance of their support, we can create a matrix guide for the communications strategy.  6. Maintaining an updated stakeholder analysis and communication plan  Stakeholder management is a continuous process that evolves throughout the project. It is critical to review the stakeholder analysis and communication plan upon identifying a solution. Additional stakeholders might come into play. The relationship with them might change. All these changes need to be documented using a document such as a Stakeholder Analysis and Communication Plan. | | | | | |
| Associated evidence | | | | | |
| I have manage stakeholders of different projects and ventures for instance when introducing a new technology at the AMRC.  1. Identifying stakeholders:  I used the SIPOC diagram and brainstorming to identify stakeholders. Then I classified them.   |  |  |  |  |  | | --- | --- | --- | --- | --- | | Suppliers | Inputs | Process | Outputs | Customers | | Machine supplier  Abrasive supplier | Materials  Risk Assessment | Bacterial inspection  Installation  Maintenance  HS Inspection | Parts  Inspection reports | AMRC Partners  SMEs |   Internal: H&S, Quality, Maintenance, Head of Groups, Operator, Researcher  External: WARDJet, GMA, Rodol  Interface: Business Manager, CTO, CEO, Marketing  Primary: HVMC, AMRC Partners, Innovate UK  Secondary: Nottingham University, MTC, Flow, WJS  2. Prioritise stakeholders:  I use the “Power/ Interest” matrix to prioritise stakeholders:    3. I have defined the stakeholders impact  4. I have determined the stakeholders current attitude  5. I have developed a communication plan (influence strategy).  6. The above has been documented in a stakeholder Analysis and Communication Plan (summarised below) | | | | | |

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| Index | 20.1 | Table | B.2 | Original index | 3.1 |
| Competency | | Communication skills | | | |
| Performance criteria | | Understand importance, uses and builds skills in others | | | |
| Understanding the competency | | Can describe the importance of communication skills in Lean & Six Sigma implementations and consequences of poor communication. | | | |
| Applying the competency | | Has evidence of the use of appropriate communication approaches with teams and individuals. | | | |
| Managing the competency | | Has evidence of planning, initiating and progressing appropriate communications. | | | |
| Training the competency | | Trains communication approaches. | | | |
| Competence statement | | | | | |
| The success of any project including Lean & Six Sigma involving more than one person highly depends on the success of communication. Communication is a process where first ideas are generated in someone’s mind and passed on to other people. If communication is not successful this can generate a form of Muda where generation of extra work, losses of quality (or even business) can occur. Miscommunication can happen within the various forms and means of communication (non-verbal, verbal, written, technology –e.g. software, etc.); cultural or because of difference of languages.  Good communication is essential for:   * Working with a team. The team leader should be able to communicate will with every member that is involved in the project in order to convey each team member their role and expectations; avoiding misunderstandings (waste). Motivation can also be achieved by means of good communication. Empowered team members who are aware of the impact their tasks have on the outcomes are more motivated than people working without knowing the results of their actions. * Understanding customer requirements. The “voice of the customer” is at the core of Lean and Six Sigma projects. Continuous improvement projects are led by the VOC, if this is not understood the projects would be tackling the wrong problems, hence muda will be created. * Deal with barriers of implementation. Unless the benefits of Lean and Six Sigma are clear, there will be resistance to change. By communicating about the positive results of continuous improvement programmes, Black Belts can strengthen morale of people and enlist their support for the change. Communicating the proposed actions and having a two-way communication/interaction will aid in the implementation process. * Educating people in Lean and Six Sigma. Having a basic level of Lean & Six Sigma training empowers employees at varying levels to put their observations into practise or suggestions for further improvement. Knowing the philosophies will also make them understand why change is needed and they may be more willing to implement. * Explaining stakeholders of how Lean & Six Sigma projects will affect them. This extends from the different teams and departments of the organisation to the customers and suppliers. * Leaders to equip Lean and Six Sigma teams with information needed. Company leaders must be able to communicate all the tools and information necessary to apply Six Sigma concepts to their daily activities. Clarifying the rationale, expectations, goals and sequence of steps in the process is essential for the success of Black Belts in their projects. Goals, objectives, time-frame, roles and responsibilities need to be made evident and transparent.   The more complex a work environment becomes, the more important it is or all parties to communicate effectively. Communication muda has increased due to the increase complexity and globalisation of today’s business systems. Whenever the communication process breaks down, and miscommunication occurs, it almost always leads to non-value-added activity (waste). Top priority to understand customers’ expectations and requirements. Lack of clarity in communicating business information is probably more responsible for underachievement than other factors.  The way people receive news and information can dramatically affect what their reaction to it. For instance, sometimes e-mails can feel a bit impersonal or cold; whereas personal communication is a bit friendlier. | | | | | |
| Associated evidence | | | | | |
| Since implementing Lean & Six Sigma usually involves changing human behaviour, it is critical to include a carefully constructed communication plan that identifies and addresses human concerns. I have used a communication plan to help record who are the most important stakeholders in the project and their communication details (emails, phone numbers), how to communicate with stakeholders (preferred channels), when to communicate (daily, weekly).    I have planned meetings with project stakeholders. I have used different means of communication such as emails and telephone conversations. My prefer method of communication is face to face meetings, if possible. Skype calls or Webex are good as you can have video streaming and share your computer screen for others to see. After the meeting I like to summarise actions in a follow up meeting or in meeting minutes.    I have trained my team (Researcher and student) on communication approaches. My researcher was involved in a process improvement project where he had to buy some tools with a long lead time. I asked him to identify the stakeholders of the project and prepare a communication plan. Then I asked him to contact the tool suppliers and communicate the need for more involvement based on the benefits of the project to other stakeholders and the business opportunity for the tool supplier. After he talked to them there was more engagement of the tool supplier with the team. | | | | | |

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| Index | 20.2 | Table | B.2 | Original index | 3.2 |
| Competency | | Change effect on individuals | | | |
| Performance criteria | | Can describe change curve | | | |
| Understanding the competency | | Can explain change curve thinking and its effect on any change including Lean & Six Sigma implementation | | | |
| Applying the competency | | Has evidence of analysis of situation based on understanding of change process. E.g. transition curves / change curves to help explain attitudes and / or actions of self or team | | | |
| Managing the competency | | Has evidence of analysis of situation and planning of actions based on understanding of change process, e.g. transition curves / change curves. | | | |
| Training the competency | | Train others in the need for cultural change. | | | |
| Competence statement | | | | | |
| Process improvement projects will likely end up having an effect on individuals. Lean Six Sigma managers must recognise that people are emotionally affected by the project efforts and outcomes. A failure to consider the effect on individuals could be one reason why the project can derail.  A model that can be used to understand change effect on individuals is the Change Curve. It describes stages of individuals’ transition and organisational change. It helps predict how people will react to change, so they are managed and supported throughout the transitions.  The Change Curve model describes six stages that most individuals go through as they adjust to change. The first stage is when the change is introduced. The individual first reaction is shock and denial. Common behaviours are to blame others and to keep the status quo. The second stage is when individuals become more critical about themselves taking the blame. There is resistant to change. For as long as people stay in these two stages change will be unsuccessful. These stages are stressful and unpleasant. Strategies to overcome these stages have to be developed.  The third stage is characterised by confusion and doubt. Individuals start wondering about the change, thinking how will be affected and how they may be able to overcome it. This leads to the fourth stage of acceptance where individuals stop focusing on what they have lost. They start let go and accept changes. They start learning the reality discovering the good points and the bad ones. They start adapting.  When individuals reach the fifth stage, they start accepting and embracing change. New ways of working are proposed, ideas and innovation blossom. It is in this stage that the benefits of change manifest.  By stage six the change is now the normal way, the beginning of a routine or status quo. The individual starts to become more productive and efficient. The positive effects of change become apparent. | | | | | |
| Associated evidence | | | | | |
| The Change Curve shows the stages of individuals’ stance against a change. Leaders have to facilitate the progress of individuals through the stages, if a successful change is to be achieved. The way people react to change is also affected by their personality type.  With knowledge of the Change Curve, the plan is to minimise the negative impact of the change and help people adapt more quickly to it. The aim is to minimise the curve and make the stages as shorter as possible.  As an example of change that directly affected one of the team members was the restructuration of the team. The researcher was transferred to a different team. He had to learn new skills and learn how to work in a different team in different projects.  Considering the Change Curve, stages 1 and 2 He initially was in shock and denial. I had to communicate very clearly the need of change and how this will affect his work life. I gave him time to think, reflect and adjust. I kept him informed of what was happening and asked him to come to speak to me if he needed more information. I reassured him that the change was not because he had done something wrong or his work was not good enough. We talked about the good things he had done for the team.  For stage 3, when he was in doubt and thinking about how to do well in his new team. I consider his personality, and look for ways of motivating him. I offered to be his coach and mentor. We discussed strategies for him to take initiatives within his new role. We talked about threats and opportunities. This is when he change to stage 4 when he mentally accepted his new role. He started adapting  In stage 5 we were looking at new ways in which he could contribute to his team.  He is in stage 6 now, he often comes to me for support and coaching in research methods and started taking the lead on experimental design on his new team. | | | | | |

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| Index | 20.3 | Table | B.2 | Original index | 3.3 |
| Competency | | Change at organisational level | | | |
| Performance criteria | | Importance of cultural change | | | |
| Understanding the competency | | Can explain the importance of cultural change in Lean & Six Sigma implementation, rather than individual change or process change. | | | |
| Applying the competency | | Written evidence of identification of analysis of cultural state and identification of cultural issues which need to be addressed. | | | |
| Managing the competency | | Written evidence of identification of possible issues, of challenges encountered in practice and any plan of action required as a result. Evidence of action taken, including monitoring of effectiveness and refinement of plans. | | | |
| Training the competency | | Trains others in the need for cultural change. | | | |
| Competence statement | | | | | |
| Change at organisation level means a difference in a present state compared to an earlier one in the overall work environment of an organisation. It is transforming or converting something, becoming different. Organisational change may mean changing technological infrastructure, marketing strategies, management and decision-making practices. Change often results from the pressure of forces which are both outside and inside the organisation. External factors such as globalisation, expanding markets, government policies, new ways of doing business, technology are drivers for change. Internal factors such as a focus on internal efficiency and process improvement can lead to organisational change. As a result, organisations have to revise corporate missions and goals, management practices, and day-to-day business functions.  The ultimate organisational change is a change in culture. Culture is the commonly hold ideas, beliefs and practices within a collective; the commonly known stories of the organisation, the rituals, the organisation of the workspace, office design. Organisational culture is a way of thinking, behaving or working that exists in the organisation. It is maintained through language, material objects and practices. Organisational culture determines how managers and employees perform in order to fulfil company goals according to the strategy and values. Culture affects every aspect of each person’s job, including decision-making practices, organisational reaction to crisis, evaluation criteria and practices for allocating rewards, hiring promotions and management development practices.  There are four primary indicators of major organisational change:   * Change in organisational structure: for example through downsizing, outsourcing, acquisition or mergers. There may be layoffs, or change in roles. * New product or service: with implications for changes in production, sales and customer service. New competitors and new markets will also allow for change. * New management: such as change in Chief Executive Officer brings a period of transition which managers are likely to alter existing business processes and personnel policies. * New technology: can change processes or working conditions which may influence the skills that employees use on the job. | | | | | |
| Associated evidence | | | | | |
| As an example of analysis of cultural state and identification of cultural issues is the Gender and Diversity project I am collaborating. The project involves uncovering the AMRC’s “Gender and Diversity Culture”, identify the issues at organisational level, propose actions for change, measure the impact of the actions on the AMRC Gender and Diversity culture and control the processes made (DMAIC).  In order to assess the issues data from HR (staff numbers, promotions, recruitment, maternity leave and turnover) were analysed. A confidential staff survey was designed and circulated with the aim of finding out staff views on Gender and Diversity.          Some responses from the survey:          The survey revealed that a high percentage of AMRC staff were not aware of the Athena Swan Charter. As an action an information pack was designed and distributed on the AMRC intranet. In addition, managers were asked to mention the project in their review meetings.    A second survey is on its way in order to assess changes that the Athena Swan project have incited in the AMRC culture.  I am a member of the Athena Swan Charter Self-Assessment Team, as such I am responsible to communicate the need of cultural change with respect to Gender and Diversity at the AMRC. | | | | | |
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| Index | 21 | Table | A.2 | Original index | 21 |
| Competency | | Statistical techniques | | | |
| Performance criteria | | To understand statistical techniques and methods and use appropriately. | | | |
| Understanding the competency | | Describes categories of statistical techniques for process improvement such as the following: descriptive statistics, inferential statistics, exploratory data analysis (EDA). | | | |
| Applying the competency | | To demonstrate the appropriate application of statistical techniques and methods in process improvement. | | | |
| Managing the competency | | Review the use of statistical techniques in process improvement. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Six Sigma projects use numbers, data and measurements to achieve, control and maintain process improvement. Statistics is the mathematical tool for transforming data into knowledge. It helps create a data-leveraging environment in which we gain the utmost value from the information available. Statistics is a branch of mathematics dealing with the collection, analysis, interpretation, presentation, and organisation of data.  In statistics *population* refers to all members of a defined group that we are studying or collecting information on for data-driven decisions. It is typically not feasible to measure a characteristic on the entire population and in order to study the population a certain number of data are selected. These data are termed a *sample*. A sample is usually analysed producing *statistics* that are used to estimate the corresponding *population parameters*. Sample statistics are indicated using Latin letters whereas population parameters by using Greek letters. The following Table lists commonly used symbols.   |  |  |  |  |  | | --- | --- | --- | --- | --- | |  |  | **Population** | **Sample** |  | |  | Sample size | N | N |  | |  | Mean | μ | X |  | |  | Standard deviation | σ | S |  |   Data collected can be put into a table that displays the frequency of outcomes, thus counting the occurrences of values within a particular group or interval. This table summarises *the frequency distribution* of values in the data. The following Table provides an example of frequency distribution for continuous data (left) and for interval data (right).   |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | | **Rank** | **Degree of agreement** | **Frequency** |  | **Weight in kg** | **Frequency** |  | | 1 | Strongly agree | 20 |  | 40-44 | 2 |  | | 2 | Agree somewhat | 30 |  | 45-49 | 4 |  | | 3 | Not sure | 20 |  | 50-54 | 5 |  | | 4 | Disagree somewhat | 15 |  | 55-59 | 8 |  | | 5 | Strongly disagree | 15 |  | 60-64 | 5 |  | |  |  |  |  | 65-69 | 4 |  | |  |  |  |  | 70-74 | 2 |  |   A common method of showing frequency distributions is by constructing a graph called a *histogram*. A histogram shows the distribution of all observations in a dataset. It is useful for describing the shape, centre and spread to better understand the distribution of the dataset. In a histogram the height of the column relates to the frequency of a range of values. Columns are usually the same width, although they can be constructed using unequal ranges for interval data. The values represented in each column must be mutually exclusive and exhaustive; i.e. one observation belongs solely to one bar. There are no spaces between bars. The following Figure provides an example of a histogram.    Figure Histogram  Other type of visualising a frequency table is by means of a bar chart. A bar chart is a type of graph in which each column represents a categorical variable or a discrete ungrouped numerical variable. It is used to compare the frequency for a category or characteristic with another category or characteristic. In a bar chart, the bar height shows the frequency for each category or characteristic. A bar chart does not show the distribution of the data as each column represents an individual characteristic rather than intervals or continuous measurements. There are spaces between bars. An example is shown in the following Figure.    Data from processes and nature is characterised by some type of structure or shape. By analysing a histogram the shape of the distribution can be discovered. Various types of distributions have been classified and studied:   * Normal distribution (or Gaussian): has the shape of an inverted “U” commonly referred as “bell shape”. The normal distribution is one of the most used as it occurs naturally in many situations (e.g. height, IQ, weight of humans; measurement errors.) * Poisson distribution: Results of processes such as web pages hits, people queuing for bus stops or services, amount of emails received each day. * Binomial distribution: Results from a number of successes in experiments, answering a yes/no question. For instance on a pass or no pass inspection.     Statistical distributions can be characterised by measuring central tendency and variability (or spread). Measurements of central tendency describe the centre position of a distribution for a data set. They include the mean, median and mode. Measures of variability, or the measures of spread, aid in analysing how spread-out the distribution is for a set of data. They include the standard deviation or variance, the minimum and maximum variables, range, quantiles, the kurtosis and skewess.  A statistical analysis that investigates central tendencies and data distribution is called **descriptive data analysis**. The objective is to summarise the measurements in a single data set without further interpretation. It presents the data in a way that facilitates their understanding by representing the data with coefficients. Outputs of a descriptive data analysis are:   * Calculate central tendency (mean, mode) * Calculate variability * Make tables * Understand data distribution (normality)   An **exploratory data analysis** usually follows from a descriptive analysis. Exploratory analysis is largely concerned with summarising and visualising data before performing formal modelling. It intends to search for discoveries, trends, correlations, or relationships between the measurements of multiple variables to generate ideas or hypotheses. Exploratory analysis tries to understand the properties of the data, inspect qualitative features rather than a huge table of raw data. Outputs of an exploratory analysis are:   * Build graphs * Identify relationships, correlationships and patterns * Identify outliers, confounders, missing data   An **inferential data analysis** goes beyond an exploratory analysis by quantifying whether an observed pattern will likely hold beyond the data set in hand. Inferential data analyses are the most common statistical analysis in the formal scientific literature. The goal is to identify the strength of the relationship in both the specific data set and to determine whether that relationship will hold in future data. In-non randomised experiments, it is usually only possible to observe whether a relationship between two measurements exits. It is often impossible to determine how or why the relationship exits. It could be due to unmeasured data, relationships, or incomplete modelling (i.e. correlation does not imply causation). Useful tools for inferential data analysis are:   * Hypothesis testing * Linear regression * Multi-variate analysis * Design of Experiments   A **predictive data analysis** takes the inferential analysis further. It uses a subset of measurements (features) to predict another measurement (outcome). The predictions are usually carried out using data not considered in the model development. Example of predictive analysis tools are:   * Machine learning * Decision trees * Artificial Intelligence * Data mining * Design of Experiments   A **causal data analysis** seeks to find out what happens to one factor if you make another factor change. Unlike a predictive or inferential data analysis, a causal data analysis identifies both the magnitude and direction of relationships between variables.  A **mechanistic data analysis** seeks to demonstrate that changing one measurement always and exclusively leads to a specific, deterministic behaviour in another. The goal is to not only understand that there is an effect, but how that effect operates. The following Figure summarises the data analysis techniques. | | | | | |
| Associated evidence | | | | | |
| An example of the use of statistical techniques for process improvement is when I used linear regression to model the taper angle of a water jet process and develop a taper compensation. When cutting a thick material with a water-jet machine, a surface with an angle different to 90 degrees is usually formed. This angle is termed “taper angle”. If a 90 degree surface is needed a low cutting speed can be selected (increasing cutting time). The problem acerbates due to the fact that lower speeds have to be programmed when going around curved features or an entry or exit of the cut. This would translate in a different taper angle in different parts of the component. However, modern water jet machines have the capability of 5-axis which means that if we understand the relationship between taper angle and traverse speed, we can compensate. So building a model (excluding the error term) in the form of:  y = B0 + B1 x  where y is the taper angle, x is the traverse rate and B0 and B1 the coefficients; will allow us to know by how much to tilt the water-jet head to compensate for taper at different traverse rates. If this is possible higher productivity will be achieved.  I carried out experiments with different traverse rates and measured taper angle (amongst other variables). I used R for data analysis. A summary of descriptive statistics is shown below.   |  | | --- | | summary(x)  Min. 1st Qu. Median Mean 3rd Qu. Max.  20.00 77.75 107.00 102.04 131.25 200.00  > summary(y)  Min. 1st Qu. Median Mean 3rd Qu. Max.  -0.1600 0.5900 0.7800 0.6779 0.8925 1.0600 |   Traverse rate was changed from a minimum of 20 mm /min to a maximum of 200 mm/min. The resulting taper angle had a minimum of -0.16 and maximum of 1.06 degrees, with a mean of 0.678 degrees. A quick plot to explore the data reveals that indeed there seems to be a relationship between taper angle and traverse rate.   |  | | --- | | plot(x, y, xlab = "Traverse Rate, mm/min", ylab = "Taper angle, degrees") |     The graph suggests that taper angle increases linearly with traverse rate so I fitted a linear regression model. A summary of the model is displayed below.   |  | | --- | | > relation = lm(y~x)  > summary(relation)  Call:  lm(formula = Taper$Taper.angle ~ Taper$Traverse.Rate)  Residuals:  Min 1Q Median 3Q Max  -0.28909 -0.07276 0.01334 0.10387 0.26975  Coefficients:  Estimate Std. Error t value Pr(>|t|)  (Intercept) -0.0047021 0.0673813 -0.07 0.945  Taper$Traverse.Rate 0.0066894 0.0006098 10.97 2.98e-11    (Intercept)  Taper$Traverse.Rate \*\*\*  ---  Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1  Residual standard error: 0.1369 on 26 degrees of freedom  Multiple R-squared: 0.8223, Adjusted R-squared: 0.8155  F-statistic: 120.3 on 1 and 26 DF, p-value: 2.981e-11 |   The ‘Residuals’ provide the difference between the experimental and predicted data. From the model we can see that the value for the coefficient B0 is -0.0047 and for B1 is 0.0067, their standard error and a t-value and probability for the null hypothesis that the coefficients have values of zero. We see that there is no evidence that Bo is different from zero and strong evidence that B1 is significantly different as the p-value is less than 0.005. The R-squared and Adjusted R-squared for the model are also shown. The value of both of, greater than 0.8, provide evidence of a good model fit and prediction power.  For visualisation, the model can be plotted alongside the data.    I carried out extra experiments to test the model. The experiments were carried out for a traverse rate of 60 and 80 mm/min with tapers resulting on 0.41 and 0.56 degrees, which are in agreement with the model predictions.   |  | | --- | | > newdata = data.frame(x = c(60,80))  > newdata  x  1 60  2 80  > result = predict(relation, newdata, level = 0.9, interval = "confidence")  > result  fit lwr upr  1 0.3966628 0.3345562 0.4587694  2 0.5304511 0.4807414 0.5801608 |   The taper compensation was applied by relating the traverse rate to the machine head angle using the linear regression model. This allowed increased productivity. The following image shows a simulation of the taper compensation algorithm. The different colours in the surface represent the amount of material “overcut” to compensate for taper angle. Notice that less compensation is needed close to the corners as the traverse rate is reduced. | | | | | |

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| Index | 22 | Table | A.2 | Original index | 22a |
| Competency | | Statistical software use | | | |
| Performance criteria | | To have knowledge of the application and capabilities of their statistical software tool and situations when it is appropriate to use it. | | | |
| Understanding the competency | | Describe the use and capabilities of one statistical software package. | | | |
| Applying the competency | | To demonstrate proficiency in at least one statistical software package currently available, including the sense checking and presentation of analysis results. | | | |
| Managing the competency | |  | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| There is a variety of statistical software that could be used to aid in the analysis of data. One popular piece of software is the R package. R is more of an integrated suite of software facilities for data manipulation, calculation and graphical display. It consists of:   * An effective data handling and storage facility, * A suite of operators for calculations on arrays, in particular matrices, * A large, coherent, integrated collection of intermediate tools for data analysis, * Graphical facilities for data analysis and display either directly at the computer or on hardcopies, and * A well developed, simple and effective programming language (called “S”) which includes conditionals, loops, user defined recursive functions and input and output facilities.   R is an open-source free software that runs on almost any standard computing platform and operating system. R has many advantages over other statistical software:   * It is open source * It is free * It creates quality graphs * It is supported by a big community that develops a variety of applications * It supports markdown * It has frequent releases | | | | | |
| Associated evidence | | | | | |
| The most commonly used graphical integrated development environment for R is RStudio. RStudio can be customised to display windows with different information. It has a console displaying a prompt “>” to provide code to be analysed. In the windows plots can be visualised, data objects can be displayed, information about packages obtained, help displayed, etc.    R operates on named data structures. Examples of them are:   * Vectors: a single entity consisting of an ordered collection of numbers, characters, logical quantities. * Matrices or arrays: are multi-dimensional generalisations of vectors. * Factors: is a vector used to specify a discrete classification. * Data frames: are matrix-like structures, in which the columns can be of different types. * Functions: can be written and stored in memory to extend R capability. A great variety of functions are already codded into the base of R * Lists: object consisting of an ordered collection of objects known as its components.   One of the strengths of R is that there exists a wide community of developers that have written code (packages) for different applications. These are extensions to the base R package which contains the basic functions that allow R to work, and the datasets and standard statistical and graphical functions. The following Table shows R Packages dedicated to Six Sigma.   |  |  | | --- | --- | | **Package** | **Description** | | SixSigma | Six Sigma Tools for Quality Control and Improvement | | qualityTools | Methods associated with DMAIC | | qcc | Quality Control Charts | | qicharts | Quality Improvement Charts |   R has several datasets built in in the R base. I will use the dataset “mtcars” to demonstrate some of R capabilities. Mtcars dataset was extracted from the 1974 Motor Trend US magazine, and comprises fuel consumption and 10 aspects of automobile design and performance for 32 automobiles.   |  |  | | --- | --- | | **Variable name** | **Description** | | mpg | Miles/gallon | | cyl | Number of cylinders | | disp | Displacement cu.in | | hp | Gross horsepower | | drat | Rear axle ration | | wt | Weight (1000 lbs) | | qsec | ¼ mile time | | vs | V/S | | am | Transmission (0= automatic, 1=manual) | | gear Number | Number of forward gears | | carb number | Number of carburettors |   I will investigate if the fuel consumption is linked to transmission. First I will perform an exploratory data analysis to visualise the data. A histogram of the mpg data can help us visualise the data. The Figure also shows a curve of the normal density plot.   |  | | --- | | > myhist <- hist(mtcars$mpg)  > multiplier <- myhist$counts / myhist$density  > mydensity <- density(m, std)  > mydensity$y <- mydensity$y \* multiplier[1]  >  > plot(myhist,xlab = "Miles per gallon (mpg)", col = c("blue"), main = "Histogram of mpg")  > lines(mydensity) |     A Shapiro-Wilk normality test can be carried out in order to test the assumption of the mpg data being normally distributed.   |  | | --- | | > shapiro.test(mtcars$mpg)  Shapiro-Wilk normality test  data: mtcars$mpg  W = 0.94756, p-value = 0.1229 |   The output of the test, displayed in Figure 37, reveals that the assumption of normality is granted, as the p value exceeds the 0.05 threshold.  A boxplot of the two variables can provide us information about the relationship between fuel consumption and transmission.   |  | | --- | | boxplot(mpg ~ am, data = mtcars,  xlab = "Type of Transmission", ylab = "Miles per gallon (mpg)",  main = "Fuel Economy vs Type of Transmission", col = c("blue", "white"),  names = c("Auto", "Manual")) |     The boxplot suggests that mean fuel consumption is higher for automatic transmission without accounting for further variables. In order to explore the relationship between fuel consumption and transmission a simple linear model is proposed.   |  | | --- | | > mtcars$am = as.factor(mtcars$am)  > fit0 = lm(mpg~am, data = mtcars)  > round(summary(fit0)$coef, 5)  Estimate Std. Error t value Pr(>|t|)  (Intercept) 17.14737 1.12460 15.24749 0.00000  am1 7.24494 1.76442 4.10613 0.00029 |   This basic model provides evidence of a statistically significant relationship between transmission type and fuel consumption, disregarding other factors, with a p-value < 0.001; as can be seen in the summary of coefficients of the model, Figure 39. This model shows that the average fuel consumption changes from 17.15 to 24.39 miles per gallon, when changing from automatic to manual transmission.  However, other variables may contribute in the variation of fuel consumption. We can create a second model including variables such as number of cylinders, horsepower and weight.   |  | | --- | | > fit1 = lm(mpg ~ am + cyl+ hp+ wt, data = mtcars)  > round(summary(fit1)$coef, 5)  Estimate Std. Error t value Pr(>|t|)  (Intercept) 36.14654 3.10478 11.64222 0.00000  am1 1.47805 1.44115 1.02560 0.31418  cyl -0.74516 0.58279 -1.27861 0.21192  hp -0.02495 0.01365 -1.82843 0.07855  wt -2.60648 0.91984 -2.83363 0.00860 |   With this second model, the average miles per gallon for an automatic transmission is 36.15 and increases to 37.63 mpg when keeping number of cylinders, horsepower and vehicle weight constant. Note that the increase attributed to transmission is not significant when adjusting for other variables.  Other variables may be included in the model. We can look for the effects of including displacement and rear axle ration.   |  | | --- | | > fit2 = lm(mpg ~ am + cyl+ hp+ wt + disp + drat, data = mtcars)  > round(summary(fit2)$coef, 5)  Estimate Std. Error t value Pr(>|t|)  (Intercept) 36.04938 7.60553 4.73989 0.00007  am1 1.37506 1.56866 0.87658 0.38906  cyl -1.03335 0.72405 -1.42718 0.16590  hp -0.02887 0.01444 -1.99909 0.05658  wt -3.27472 1.15685 -2.83073 0.00903  disp 0.01257 0.01195 1.05154 0.30307  drat 0.48586 1.49495 0.32500 0.74788 |   The three models built can be analysed by means of ANOVA.   |  | | --- | | > anova(fit0, fit1, fit2)  Analysis of Variance Table  Model 1: mpg ~ am  Model 2: mpg ~ am + cyl + hp + wt  Model 3: mpg ~ am + cyl + hp + wt + disp + drat  Res.Df RSS Df Sum of Sq F Pr(>F)  1 30 720.90  2 27 170.00 3 550.90 28.2628 3.384e-08 \*\*\*  3 25 162.43 2 7.56 0.5821 0.5661  ---  Signif. codes: 0 ‘\*\*\*’ 0.001 ‘\*\*’ 0.01 ‘\*’ 0.05 ‘.’ 0.1 ‘ ’ 1 |   From the analysis we can conclude that the inclusion of variables in model two are statistical significant. However, including displacement and rear axle ration do not produce a significant better model. We focus our attention in model two and interpret the Coefficient Table, switching from automatic to manual transmission increases mpg by 1.48 mpg (however, this is not significant at a p-value of 0.314) – increasing 1 cylinder decreases mpg by 0.75 mpg – increasing one hp decreases mpg by 0.025 – increasing 1 ton of weight decreases mpg by 2.6. Weight seems to be the most significant variable affecting fuel consumption. In order to quantify the uncertainty of our model, we calculate the confident intervals.   |  | | --- | | > confint(fit1)  2.5 % 97.5 %  (Intercept) 29.77605177 42.517019733  am1 -1.47894635 4.435041763  cyl -1.94093802 0.450623969  hp -0.05295064 0.003048517  wt -4.49383134 -0.719130075 |   From this, we can corroborate that transmission is not statistically significant with respect to fuel consumption (the confident interval contains zero) and weight has a significant effect. An analysis of the residuals of our model is presented below.  Several indicators can be used to assess the goodness of the model. One of them is the Coefficient of Determination (R2) which is the quotient of the variances of the fitted values and observed values of the dependent variable. R squared provides the percentage of variation that the model explains. The range is 0 to 1 (0-100%). For our example R2 = 0.85, which means that 85% of the variation in mpg is explained by our choice of variables (i.e. am1, cyl, hp and wt)   |  | | --- | | > summary(fit1)$r.squared  [1] 0.8490314 |   A problem encounter with R squared is that it will increase as we increase the number of predictors in our model. A better measurement is adjusted R-squared denoted Q2. This statistic will increase as we include useful predictors and start decreasing when the prediction power of the model is lowered by adding noisy variables.   |  | | --- | | > summary(fit1)$adj.r.squared  [1] 0.8266657 |   Diagnostic plots for linear regression analysis can be generated easily with R. They analyse the residuals which are leftover of the outcome variable after fitting the model to data. Residuals could reveal unexplained patterns in the data by the fitted model. Using this information, not only we check if the linear regression assumptions are met, but we can improve the model in an exploratory way.   |  | | --- | | > par(mfcol = c(2,2))  > plot(fit1, which = 1)  > plot(fit1, which = 2)  > plot(fit1, which =3)  > plot(fit1, which = 4) |     Figure Residual plots  The Residual vs Fitted plot shows if the residuals have non-linear patterns. There could be a non-linear relationship between the predictor variables and the outcome variable, if this is the case there would be a pattern in this plot. A good indication is a plot with equally spread residuals around a horizontal line, without any distinct patterns.  The Normal Q-Q plot shows if the residuals are normally distributed. Normally distributed residuals should follow a straight line.  The Scale-Location plot shows if residuals are spread equally along the range of predictors. This is usually good to check the assumption of equal variance (homoscedasticity). It is good if a horizontal line with equally (randomly) spread points is shown.  Cook’s distance plot is used to find influential outliers. Outliers have already been pointed out in the other graphs by displaying the point name. Cook’s distance identifies these points that negatively affect the regression models. Outliers should be investigated. | | | | | |

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| Index | 23 | Table | A.2/B.2 | Original index | 23/12 |
| Competency | | Sustainability and control | | | |
| Performance criteria | | To understand the concept of control in a Six Sigma project, and sustaining improvement in processes. | | | |
| Understanding the competency | | Describes the importance of sustainability of implemented solution. Describes review method, such as daily workplace audits, weekly team reviews. | | | |
| Applying the competency | | Demonstrates effectiveness of steps taken to ensure performance of improved process is sustained over time, such as workplace audits, daily after action reviews, weekly team reviews. | | | |
| Managing the competency | | Reviews the control phase of DMAIC projects. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Successful Six Sigma and Lean projects translate into improvements, visible changes in processes, measurable increased in performance. An implementation that cannot be sustained over a long term has limited value. The control phase of the DMAIC methodology ensures the sustainability of improvements in processes.  Process behaviour is complex and fragile, hard-earned gains can slip away easily if the process is left to itself. A well designed process includes a system of events, activities and feedback loops where a control mechanism can be incorporated. A well designed and implemented control plan guarantees the improved performance is sustained. There are two aspects to a control plan: monitoring of the outputs and controlling the inputs.  Some of the commonly used tools in this phase are:   * Statistical Process Control Charts: uses statistical methods to monitor and control a process. Data are plotted in time order. A control chart always has a central line for the average, an upper line for the upper control limit and a lower line for the lower control limit. * Assessing Final Process Capability: used for processes that are in a state of statistical control, measures the ability of a process to produce output within specification limits. * Revised Failure Mode and Effects Analysis: A revised FMEA will help anticipate new things that might go wrong with the improved process, finding possible causes of failure and likelihood of occurrence along with the effect in the process. * Mistake Proofing (PO-ka yo-KAY): uses process design features that makes it impossible for an error to occur or make the error immediately obvious once it has occurred. * Control Plan: documents the functional elements to be implemented in order to assure quality standards are met. * Visual Management (Mieruka): can be used to communicate performance visually. Examples are putting data on display on the shop floor to show production rate, quality defects, status of machines, marking things such as locations of tools, labels of items, etc. * Standard Operating Procedures (SOP): the set of step-by-step instructions of the new process need to be documented. * Training: Personnel who are directly affected by the project shall be trained and monitored. * Out of Control Plan: documents plans needed to take action correctly to “out of control” metrics. Course changes can then be handled effectively and steadiness is ensured in the event of new conditions. This also allows early discovery of impending causes or problems before they bring the process out of control. An OCAP table includes headings such as “Process step” / “Control Item” (input or output) / “Control method (metric, audit, etc.) / ”Responsibility” / “Specification Limit” / “Response Plan”. * Operating Rhythm: a set of pre-defined process of communication and interactions that should be present between different departments to ensure that the flow of operation is not interrupted and is controlled as intended * Audits: are good way of sustaining good practices and identifying what needs to be improved. Audits can be carried out by members of the team or (even better) by outsiders. A schedule audit will allow keeping changes implemented; an unplanned audit will increase the chances of keeping the system running. Checklists are good tools to help with audits. What questions need to be asked, what to look for. A short checklist will allow easy implementation. Make audits a mini habit so time for them is allowed. | | | | | |
| Associated evidence | | | | | |
| During a continuous improvement project involving the application of 6s in the workplace we had an external audit. One of our colleagues that was doing her green belt training performed an initial audit for us. The purpose of the audit was to identify items that should not be in the work environment (clutter) and red tag them. Also identification of health and safety issues was in the agenda.    After the audit a successful 5s project was implemented in the waterjet room working area. The workplace was organised and health and safety concerns tackled. A scheduled audit plan was programmed and displayed in a 5s responsibility waterjet room scheduled. Each member of the team had responsibilities assigned and a member of the team carried out a weekly audit to check if the tasks had been carried out.      Health and Safety audits were also implemented. The levels of legionella were monitored in the water jet tank and recorded weekly. The high pressure pipes were monitored and their status was recorded weekly. | | | | | |

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| Index | 24 | Table | B.2 | Original index | 1 |
| Competency | | Understanding and communicating expected benefits of Lean | | | |
| Performance criteria | | Able to explain the expected benefits of using Lean (overall / general terms). | | | |
| Understanding the competency | | Can explain the benefits of Lean for value streams and in organisations. Including such concepts as reduced lead time, cycle time, operating expense. Increased capacity, productivity, and quality. | | | |
| Applying the competency | |  | | | |
| Managing the competency | | Has communicated effectively to a team working in an improvement activity the benefits of Lean. | | | |
| Training the competency | | Evidence of training Lean benefits. | | | |
| Competence statement | | | | | |
| Lean, as Six Sigma, can be defined as a philosophy, a way of thinking that can be applied to every type of organisation, manufacturing or service. The goal of the lean philosophy is to eliminate waste which causes variation throughout the value stream. Lean philosophy includes continuous learning and improvement in existing processes. Lean calls for the simplification of all tasks and efforts to eliminate waste and improve flow.  One of the Lean toots used to assist in the identification and steady elimination of waste is value stream mapping. It is used to analyse the current state and designing a future state for the series of events that take a product or service from its beginning through to the customer. It is a useful technique to separate the value adding from the non-value-adding operations. Value adding is defined when a change of weight, shape, configuration, properties or attributes to materials or information is carried out. On the other hand non-value-adding is when no change occurs and activities fall into at least one of the 12 categories of waste. Value stream mapping helps identifying bottlenecks and improvement opportunities in   * Lead time reduction: Lead time is the time required to manufacture an item, including order preparation time, queue time, setup time, run time, move time, inspection time, and put-away time. It is the time from order received to shipment. Value stream mapping allows the identifying of non-value added activities for future elimination streamlining the process and reducing lead time. * Cycle time: Cycle time is the time required to complete on cycle of an operation. There are two aspects that can be reduced, the variation of cycle time and the length. Value stream mapping allow for the decomposition of a task in sub-activities which can be studied in an effort to eliminate non-value-added components and find better and faster ways to complete the value-added components. Techniques that can be used to accomplish these goals are kaizen blitz and rapid continuous improvement. * Productivity: can be defined as a relationship between output produced by a given organisational system and quantities of input utilised by the system to produce that output i.e. a ration of outputs to inputs. The inputs are usually classified as labour, capital, material and energy. Lean techniques allow to streamline the inputs to produce the same (or even more) with less resources. Techniques like 5s are usually attributed to productivity improvements. * Quality: increases by reducing defects at an early stage of the value stream map. Tools such as Quality at the Source (QATS) where employees are taught the minimum quality standard at each step of the process and empowered to correct defects or remove the defective item before value-added activity is conducted. By catching these defects earlier in the process, quality is improved and the cost of defects is reduced. | | | | | |
| Associated evidence | | | | | |
| I have experienced the benefits of lean at first hand. My research assistance and I worked on a 6s project at the water jet workshop. In order to get commitment from the rest of the team we had to explain the benefits of Lean to the operator and research student. Getting them involved and eliciting ideas from them helps in the implementation phase. People are more willing to collaborate and follow to completion if they are informed and feel that it is their project as well. We stressed the benefits of lean and the 5s project as savings in time for looking for tools, improved image of the work area, higher productivity as waste will be eliminated. Lead and cycle time reduction resulting from shorter time to realise tasks as tools will be available immediately and stored in known locations. Improved health and safety; the risk assessment was revised and actions taken to tackle potential problems. | | | | | |

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| Index | 24.1 | Table | B.2 | Original index | 1 |
| Competency | | History of Lean | | | |
| Performance criteria | | Has knowledge of the origins and development of Lean approaches | | | |
| Understanding the competency | | Can describe the origins of Lean | | | |
| Applying the competency | |  | | | |
| Managing the competency | |  | | | |
| Training the competency | | Evidence of training the history of Lean | | | |
| Competence statement | | | | | |
| Lean is a systematic method for waste minimisation within a manufacturing / production system. Lean methodologies highlight what adds value to a process compared to non-value added operations.  Although there are instances of process thinking in manufacturing early in the history of production. The history of Lean can be said to have started with the concept of interchangeable parts popularised in the 1800s by Eli Whitney, the inventor of the cotton gin. Whitney developed this concept in about 1799 when he took a contract from the U.S Army for the manufacture of muskets.  The next century witnessed the development of technology that gave birth to specialised machine tools, engineering drawings and large scale processes such as the Bessemer process for making steel. There was a focus on processes with little attention to a system’s view i.e. what happened between processes, how multiple processes were arranged within the factory, material flow, standardisation of work, etc.  In 1890’s Scientific Management was born with the ideas of Frederick W. Taylor and Frank Gilbreth. They started studying the individual workers’ movements and work methods, standardising work. However, disregarding the behavioural psychological side. This was later studied by Lillian Gibreth who looked at how motivation affected the outcome of processes.  In 1910, Henry Ford and Charles E Sorensen were the first reported comprehensive manufacturing strategy. They integrated all elements of a manufacturing system (people, machines, tooling and products) and arrange them in a continuous system for manufacturing the famous Ford T Model automobile. Later on the “Ford assembly line” was emulated by other companies like General Motors, used for a military advantage in World War II for the production of bombers, and gradually popularised.  After the Second World War, in 1949 to 1975, the success of the manufacturing of the Bombers caught the attention of the Japanese industrialists. They took elements of the Ford system and added other techniques and looked at the shortcomings for instance with respect to workforce. They discovered that factory workers had far more to contribute than just muscle power. Quality Circle movements, began, Deming and Juran added major contribution to the Japanese manufacturing. The Toyota Motor Company driven by Taichii Ohno and Shigeo Shingo, incorporated these concepts in their production system recognised now as The Toyota Production System or Just-in-time.  A shortcoming of the Ford system was that it was built around a single product. Customers demanded different variations of the product, drivers which developed the TPS further. Shingo, worked on reducing setups allowing for small batches and almost a continuous flow with more flexibility. The system spread in Japan.  In the 80s the works of Ohno and Shingo were translated into English transferring the knowledge into “the Western world”. The TPS (or some aspects of it) was successfully applied into manufacturers such as General Electric. Several names started to proliferate the manufacturing strategy literature such as Stockless Production, Continuous Flow Manufacturing, etc. The phrase Lean Manufacturing first appeared in the 1991 book by James P. Womack, Daniel T. Jones and Daniel Roos, “The Machine That Changed The World”. | | | | | |
| Associated evidence | | | | | |
| I have undertaken training on the history of Lean in both my Yellow and Green Belt training. | | | | | |

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| Index | 25 | Table | B.2 | Original index | 1.1 |
| Competency | | Applying the knowledge in practice | | | |
| Performance criteria | | Can translate benefits to the specific situational environment. Identifying the issues in real organisations which affect quality, cost and delivery, and designing improvements. | | | |
| Understanding the competency | | Explains how Lean can benefit the specific environment or sector, what will/does Lean deliver to the individual’s organisation and its customers / stakeholders. | | | |
| Applying the competency | | Has evidence in a specific situation of diagnosing the areas where benefits will be delivered and to which stakeholders. Evidence of using tak times, cycle times and staffing requirements. Can identify best repeatable times for processes operations. | | | |
| Managing the competency | | Evidence of managing others to apply Lean thinking. Can explain how Lean can be applied to the specific environment or sector; what will / does Lean deliver to the individual’s organisation and its customers. Can understand and employ tak times, cycle times and staffing requirements. Can understand best repeatable times and use to budget resource requirement. | | | |
| Training the competency | | Evidence of presenting the local application of Lean approaches in the organisaiton. | | | |
| Competence statement | | | | | |
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| Associated evidence | | | | | |
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| Index | 25.1 | Table | B.2 | Original index | 1.1 |
| Competency | | Applying the knowledge in practice. | | | |
| Performance criteria | | Can demonstrate using data how much improvement will be achieved. | | | |
| Understanding the competency | | Can describe how to use data to quantify improvements. | | | |
| Applying the competency | | Has used data appropriately to demonstrate improvements. | | | |
| Managing the competency | | Has evidence of communicating benefits using appropriate data. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| The goal of Lean is to provide high quality products that meet customer expectations and to be a model of corporate responsibility. The aims of Lean are:   * Provide world class quality and service to the customer. * Develop each employee’s potential, based on mutual respect, trust and cooperation. * Reduce cost through the elimination of waste and maximise profit * Develop flexible production standards based on market demand.   A pull system is a strategy where components, parts, consumables, etc. are only replaced / produced once they have been consumed. The pull system eliminates under or over production by limiting production to those parts demanded by the next downstream process. | | | | | |
| Associated evidence | | | | | |
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| Index | 25.2 | Table | B.2 | Original index | 2 |
| Competency | | Applying the knowledge in practice | | | |
| Performance criteria | | Can describe the Lean principles | | | |
| Understanding the competency | | Can describe Lean principles define value, understanding the value stream, create flow, create “pull”, strive for perfection. | | | |
| Applying the competency | | Can apply Lean principles to a specific situation. | | | |
| Managing the competency | | Can apply Lean principles to a strategic situation. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| A lean way of thinking allows companies to “specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively”. There are five main principles of lean thinking:   * Value: defined as “capability provided to customer at the right time at an appropriate price, as defined in each case by the customer”. Value, as seen by lean; is customer, product and situation specific. This leads to a top-down target costing approach, focusing on how much a customer is willing to pay for certain products, features and services. Then the company must reduce waste and cost in order to achieve the “value” of the customer. * Value stream: defined as the “specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer”. In order to create a value stream, the activities that are carried out for the production of a process or service are described at each step, from design to order to raw material to delivery. There are three types of activities I the value stream   - Value added: activities that change the material, modifying its weight, shape or constituents or adding information. I.e. processing.  - Type one muda: activities that create no value but seem unavoidable with current technologies or production assets.  - Type two muda: activities that create no value and are immediately avoidable.   * Flow: defined as the “progressive achievement of tasks along the value stream so that a product proceeds from design to launch, order to delivery and raw materials into the hands of the customer with no stoppages, scrap or backflows”. This translated into abandoning the traditional batch-and-que model for a system that enables quick change of tools in manufacturing, locating sequential steps together to allow for elimination of waste. * Pull: defined as a “system of cascading production and delivery instructions from downstream to upstream in which nothing is produced by the upstream supplier until the downstream customer signals a need”. This is in contrasts with pushing products through a system, which is unresponsive to the customer and results in unnecessary inventory build-up. A pull system ensures that nothing is made ahead of time and produces work-in-process inventory that stops synchronised flow. * Strive for perfection: defined as “complete elimination of muda so that all activities along a value stream create value”. This implies that lean is a never-ending process. Always identifying and removing waste and targeting root causes of poor quality. | | | | | |
| Associated evidence | | | | | |
| Lean thinking represents one school of thought in manufacturing. It complements other manufacturing management concepts such as Six Sigma, Continuous Improvement and Total Quality Management in a way that waste is eliminated. The principles of Lean put the entire value stream under the microscope, allowing examining step of the process in order to correctly specify value as defined by the customer, making the process flow continuously along the whole length of the stream as pulled by the customer in pursuit for perfection.  An application of Lean principles to a strategic situation was when working for a customer to produce cage bearings.  Value: I had various meetings with the customer where we discuss the value according to their specification, standards and expectations. We discussed the costing of the cages based on a mutual understanding of the volume, quality and service provided. The customer provided me with specifications in various documents and emails.      Value Stream Mapping: The exercise of VSM provided me with the opportunity to identify value added and non-value added activities. It allows the opportunity to work with the supplier to improve their process. In particular, the identification for the need to deburr the component prior to setting it up on the machine provided extra work for us. The deburring process could be automated by the supplier. Additionally, the top face of the component was not fully machined, making it difficult for us to set up the part on the machine.    Flow: was achieved in the manufacturing of cages by designing and implementing a modular fixture which allowed for the batch size to be one. The modular fixture facilitated quick change overs by being able to accommodate cages of various sizes.    Pull: We set up a pull system where the customer demanded cages, the supplier produced the raw material for us and shipment was carried out.  Strive for perfection: Continuous work was carried out in order to improve the process, reducing time in value added operations and eliminating non-value added activities. | | | | | |

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| Index | 25.3 | Table | B.2 | Original index | 2.1 |
| Competency | | Applying the knowledge in practice | | | |
| Performance criteria | | Value | | | |
| Understanding the competency | | Defines value in the eyes of the customer, the transformation of an unsatisfied need to a satisfied need, can be a product or a service. Can identify and describe value-added activities (VA), non-value-added (NVA) process issues such as waste, unevenness, overburden (Muda, Mura, Muri) and necessary non-value added activities (NNVA). Acronyms such as DOWNTIME may be useful in waste identification. | | | |
| Applying the competency | | Has evidence of eliminating waste from processes. | | | |
| Managing the competency | | Can manage value in the eyes of the customer, identifying what is value add and what is non-value add. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Lean focuses on waste elimination. Waste, referred as muda, is anything that does not add value to a product or service, hence has no value for the customer. There are various types of muda, some of them are obvious and some of them hidden. The Toyota Production System identified seven types of muda. Later on, a further one was included. The acronym DOWNTIME is often used to remember the 8 types of muda:   * DEFECTS (Correction / Scrap): correction of defects as a result of poor internal quality making use of resources which will add to the cost of manpower, materials, facilities and conveyance measures. Defects tend to be the result of poor quality control, poor documentation, misunderstanding of customer needs, poor design, etc. * OVERPRODUCTION: There are two types of overproduction: producing too much and producing too early. The solution to overproduction is to establish a work flow based on downstream demand. Overproduction causes waste such as necessity for extra materials, increase in storage space, increase in control of stock cost, etc. * WAITING: stopping production due to waiting caused by breakdowns, changeovers, delays, poor layout, etc. Waiting increases cycle time. * NON-UTILISED/ UNDERUTILISED TALENT: This type of waste is not mentioned in the Toyota Production System. However it has been identified as part of the people side. Poor utilisation of existing talents, ideas, abilities and skills is a waste. This type of waste can be caused by issues such as: lack of teamwork, lack of training, poor communications, narrowly defined jobs and expectations, poor management. * TRANSPORTATION (Conveyance): Unnecessary movement of things around due to inefficient layouts and facility designs. Material should progress from one cell or position to the next as quickly as possible without stopping at any intermediate storage place. * INVENTORY: The aim of a Lean system is for the process to flow, minimising the amount of work-in-progress inventory or buffer inventory. The ideal system is a just-in-time, where production is pulled by demand. Inventory ties up assets such as cash and real estates, requires additional handling which translates in additional labour and equipment. * MOTION: Wasted motion occupies time and energy. Ideally all unnecessary movements or actions are eliminated from the work process. Work processes should be designed so that items are positioned close to each other. * EXCESS PROCESSING (Processing): Over processing is as wasteful as insufficient processing. Unnecessary effort spent to achieve a task, steps not needed, etc. Excess processing can arise from: poor process control, lack of standards, poor communication, human error, etc.   Aside from muda, the Lean philosophy recognises mura (overload or overburden) and muri (unevenness). Mura refers to overloading an equipment, facility, or human resource beyond its capacity. This undue stress may cause downtime, defects, delays, and even disaster. Muri refers to unevenness in production volume. Fluctuations in demand due to extreme high and lows in production scheduling causing periods of overload and long idle time. Muda, mura and muri cause inefficiencies in the system translating in unnecessary costs that the customer is not willing to pay for it i.e. non-value added. | | | | | |
| Associated evidence | | | | | |
| I have identified and eliminated sources of WASTE (muda). An example is the elimination of waste due to defects. As part of production of cage bearings cut by water jet, we identified some non-conformance. The dimensions of the pockets were out of specification. An investigation took place in order to find out the root cause and eliminate the waste (non-conformance). The waste was tracked to be a machine issue. The manufacturer of the machine was brought to solve the problem. Three main actions were taken.   1. The homing software routine of the machine was updated. 2. The tool length calibration procedure revised. 3. The cutting head was mechanically aligned.     Additional sources of waste that were identified and resolved were:   * Minimising distance between abrasive sacks and machine abrasive container. * Minimising distance between commonly used tools and operator. * Optimising machine parameters to achieve surface roughness without overproducing. | | | | | |

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| Index | 25.4 | Table | B.2 | Original index | 2.2 |
| Competency | | Applying the knowledge in practice | | | |
| Performance criteria | | Value stream | | | |
| Understanding the competency | | Understand the value stream and the boundaries of implementation. The value stream defining the stages of transformation and the wastes along the journey, usefully described by a value stream map or material and information flow map. | | | |
| Applying the competency | | Has evidence of building a current state value stream map or material and information flow map from a live process, populating with appropriate stages, flows and numbers, building a future state value stream map. | | | |
| Managing the competency | | Manages the value stream and can follow and critique a value stream map or material and information flow map of a live process. | | | |
| Training the competency | | Training others in value stream thinking, including how to create a value stream map or material and information flow map. | | | |
| Competence statement | | | | | |
| Originated in Toyota and referred to as “Material and Information Flow Mapping”, use to show current and future sates as part of the lean deployment process. It can be applied to any process and industry such as healthcare, software development, finances, administrative, etc. VPN is used to analyse and design flows at system level. VSM documents all the actions required to bring a product or service through to the customer. This looks at the production flow from customer demand back through raw material   * Identify how value flows to the customer * Define relationships among key process points * Documents current state process * Basis for developing a future state * Helps identify opportunities for improvement * Makes areas of waste visible * Shows the linkage between information flow and material flow. | | | | | |
| Associated evidence | | | | | |
| I have trained Yellow Belts in the value stream thinking for identifying waste. I have trained them to use the tool and apply it in their operational area. For hard evidence see link below. | | | | | |

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| Index | 25.5 | Table | B.2 | Original index | 2.3 |
| Competency | | Applying the knowledge in practice | | | |
| Performance criteria | | Flow | | | |
| Understanding the competency | | Creates flow, removes the barriers, identified through even wastes (Muda), removal of work in progress between process stages. | | | |
| Applying the competency | | Creates flow, can identify and remove the barriers, identified through eight waste (Muda), removing work in progress between process stages and laying out the workplace to improve flow; uses techniques such as value stream maps/ material and information flow map, spaghetti diagrams, work combination charts, workload levelling, Ohno circles to identify and remove Muda (waste). | | | |
| Managing the competency | | Flow, can identify and manage the removal of the barriers identified through eight waste (Muda) improving flow. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
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| Associated evidence | | | | | |
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| Index | 25.6 | Table | B.2 | Original index | 2.3 |
| Competency | | Applying the knowledge in practice | | | |
| Performance criteria | | Flow | | | |
| Understanding the competency | | Can describe how to use workload levelling techniques to improve flow | | | |
| Applying the competency | | Has evidence of review of process flow to identify where workload levelling would be | | | |
| Managing the competency | |  | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
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| Associated evidence | | | | | |
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| Index | 25.7 | Table | B.2 | Original index | 2.4 |
| Competency | | Applying the knowledge in practice | | | |
| Performance criteria | | Pull | | | |
| Understanding the competency | | Can describe “pull”, giving the customer what they need, when they need it. A familiar term would be Kanban relating to a signal from a customer commencing the transformation process. | | | |
| Applying the competency | | Can demonstrate creation of pull in a process, giving the customer what the need, when they need it. Uses Kanban techniques to transmit the signal from a customer to the process. | | | |
| Managing the competency | | Can manage “pull”, giving the customer what they need, when they need it. Deploys Kanban techniques to transmit the signal from a customer to the process. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
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| Associated evidence | | | | | |
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| Index | 25.8 | Table | B.2 | Original index | 2.5 |
| Competency | | Applying the knowledge in practice | | | |
| Performance criteria | | Can describe what it means “to strive for perfection” | | | |
| Understanding the competency | | Can describe the strive for perfection, starting from a standardised process, making continual improvements, in quality, cost and delivery, relentless desire to remove waste from the current state and to sustain improvements, seeking an improved next current state every day. | | | |
| Applying the competency | | Has applied standard work to processes, making repeated improvements, in quality, cost and/or delivery, relentless removal of waste from the current state seeking an improved next current state every day. | | | |
| Managing the competency | | Strive for perfection, demonstrates continual improvements, in quality, cost and delivery, relentless removal of waste from the current state seeking and improved net current state every day. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Striving for perfection is one of the fifth principles of Lean Thinking. It is the constant re-examination of the value stream in order to find waste and opportunities for improvement. This examination extends to all areas of the organisation, self and others. It is constantly looking for opportunities for improvement through Kaizen and Plan-Do-Check-Act. Striving for perfection is a state in which every single action in the organisation creates value for the customer.  As we go through the process of value stream mapping, layers and layers of muda are stripped away; only to discover more muda. Lean Thinking has to be seen in a dynamic environment where there is constant change. Customer demand and requirements can vary, which will lead to a new understanding of critical-to-quality characteristics, new demands. Novel technologies are introduced which will aid process to be carried out in a more efficient manner. New staff or staff skills might become available, which will require the utilisation of their talent.  There are always opportunities for improvement. By establishing a culture of striving for perfection, where opportunities of improvement are constantly sought, by analysing the value stream, having a good understanding of the voice of the customer, voice of the market, voice of the processes, voice of the technology, the implementation of the fifth Lean Thinking principle may be realised. | | | | | |
| Associated evidence | | | | | |
| I apply the principle of striving for perfection at my work and everyday life every day. By following the Plan-Do-Check-Act method I always make observations of how things can be improved. I am very customer focused and try to analyse the customer’s requirements by different means: surveys, emails, personal conversations. I also spend some time reflecting on the tasks that can be improved and why things do not go according to plan. As part of this plan phase I also look at lessons learnt. Additionally, I keep up-to-date with knowledge in my area, which shows some insights on different techniques and methods that can be used to improve my and the teams work.  I like applying changes according to the new knowledge on technology on processes, techniques, customer requirements, and lessons learnt. I am a researcher that likes to explore the effect of different variables on systems. I have implemented changes in processes by developing new manufacturing methods in a stepwise change improvement (e.g. parameters, materials, tools, techniques). I have implemented changes to procedures for instance measurement, order processing, data management. I have explored different ways of treating with customers (face-to-face, e-mails, telephone conversations).  As a scientist the part of these continuous striving to perfection, that I enjoyed the most is observing / studying (check) the effect of the changes implemented on the system variables. Not only the effect in mechanical processes but also the effect on people. I have witnessed the effect of new procedures on my team, and how the team personality had an interaction with such effects. I am always excited at progress made when we optimise parameters for cutting faster, greener and cheaper.  The improvements made, with new procedures, methods, techniques are the basis for the creation of new standards which assure the gains made are maintained and the knowledge passed to future team members. For instance, when I created new procedures for managing manufacturing information, machine calibration; I documented the changes and wrote new standards for the team members to follow ensuring consistency.  The cycle of PDCA is never completed; we use the new standards as a next starting point for our improvement cycle. I acquire new information, I implement changes, I observe outcomes and create new standards. | | | | | |

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| Competency | | Measurement of process performance | | | |
| Performance criteria | | Selecting and collecting data for process improvement. | | | |
| Understanding the competency | | Can describe the factors which are important in data collection, for example, sample size, sample timing, sampling method. | | | |
| Applying the competency | | Has evidence of selection and collection of appropriate data. | | | |
| Managing the competency | |  | | | |
| Training the competency | | Trains others in the appropriate collection methods for data. | | | |
| Competence statement | | | | | |
| Six Sigma is a data-driven approach for continuous improvement. In such, decisions are taken based on facts and statistical tests such as hypothesis testing and confidence intervals. However, for such tests to be valid, a proper data sample size needs to be acquired.  A sample is a percentage of the total population. We can use the data from a sample to make inferences about a population as a whole. For example, the standard deviation of the sample can be used to approximate the standard deviation of the population.  A number of formulae are available for working out sample size, *n*. For instance:   * Estimating the proportion *p* with an initial estimate , for z score zα/2 or za for a one-sided alternative hypothesis   Where, = proportion of the population having the characteristic, *E* = the degree of precision. If the proportion of the population is unknown, this can be approximated by using 0.5 (50/50 split). The degree of precision *E* is the margin of error that is acceptable. Setting *E* = 0.02, for instance, would give a margin of error of plus or minus 2%.   * Estimating the mean μ of a normal distribution with known variance σ2, for z score zα/2 or za for a one-sided alternative hypothesis   Where E is the degree of precision and σ the standard deviation.   * Detecting a difference of size E from the mean μ from a normal distribution with known variance σ2; for z score zα/2 or za for a one-sided alternative hypothesis   Where E = μ-μ0   * Detecting a true difference of size E between population means from normal distributions; for z score zα/2 or za for a one-sided alternative hypothesis. * Detecting a difference in the true population proportion μ. * Detecting a difference of size E between population means from normal distributions and known variances σ12 and σ22 when estimating μ1 – μ2 by ; for z score zα/2 or za for a one-sided alternative hypothesis. * Detecting a difference between two proportions; for z score zα/2 or za for a one-sided alternative hypothesis.   Where q = 1 - p  The formulas are expressed for a two-sided alternative hypothesis. If a one-sided alternative hypothesis is needed the term zα/2 should be substituted for zα.   * Detecting difference in mean for a known population   Where N is the population size. | | | | | |
| Associated evidence | | | | | |
| I have used appropriate sample size in my studies. For instance, for the Athena SWAN Charter Award, that I have been working in the past year. I investigated the mean level of employee satisfaction. I decided to base the study on a 95% confidence level. The number of employees at the AMRC is 412. We consider a margin of error of 5% and a percentage value p = 0.5    A sample size of 200 will guarantee a 95% confidence level.  Example of survey question showing number of responses.    Number of staff at AMRC    I have trained team members and yellow belts on data collection methods. I provided a yellow belt training course where delegates learnt about types of data, data collection plan and sample size determination. For hard evidence follow the link below. | | | | | |

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| Competency | | Measurement of process performance. | | | |
| Performance criteria | | Importance of communicating appropriate metrics used in Lean implementation. | | | |
| Understanding the competency | | Can describe the metric used in current state diagnosis and workload planning, e.g. customer demand, cycle times, takt, resources requirements, defect rate, failures, rework. | | | |
| Applying the competency | | Has evidence of calculation of appropriate metrics and their use to improve processes and quantify improvements. | | | |
| Managing the competency | | Manages processes or teams using appropriate metrics. Communicates such metrics appropriately to teams in visual manner. | | | |
| Training the competency | | Trains others in the appropriate use of Lean metrics. | | | |
| Competence statement | | | | | |
| Lean thinking is built on responding to changes in customer requirements to satisfy demand. In doing so the maximum amount of time in which a product needs to be produced in order to satisfy customer demand is defined as tak time. Takt time can be thought as a beat time or “heartbeat” of the process; at every beat a product is being delivered to the customer to satisfy demand.  Process cycle time is the total elapsed time from process start to process completion. This not may be equal to the total tasks time for the process, since process cycle takes into account additional time where no tasks are being performed (e.g. queuing between tasks). This total elapsed time more accurately reflects the process from a customer’s perspective, even though it may not reflect the internal cost of providing the service.  Process capability provides an indication of the process ability to produce an output within specification limits. The basic index is Cp which compares the natural tolerance of a process as 6σ and compares it to the engineering tolerances (without considering the process mean). Assuming the process distribution is normal and the process average is exactly centred between the engineering requirements Cp of 1 would give a capable process. However, to allow a bit of room for process drift, generally Cp of 1.33 is accepted. Although a Six Sigma process that produces 3.4 defects-per-million-opportunities would have a Cp of 2. The index Cpk considers the mean of the process and is more suitable for processes that are not cantered.  Process lead time is the latency between the initiation and execution of a process; the total time from the beginning to the end of the process, as defined by the customer. It is calculated by dividing the number of items in process by the completions per hour.  Process Cycle Efficiency is calculated by dividing the value-added time associated with a process by the total lead time of the process. It is a good metric to prioritise improvement opportunities. The key to improving process cycle efficiency is to reduce the lead time (the denominator in the equation).  The complementary measurement of yield for Six Sigma is defects. When a process or critical-to-quality characteristic does not perform within its specifications, it produces a nonconforming called a defect. A defect rate is calculated by testing output for non-compliances to a quality target. A defective part may need rework which accumulate extra costs. | | | | | |
| Associated evidence | | | | | |
| I have carried out process capability studies in order to determine process improvement opportunities or to benchmark processes. For example I carried out process capability analysis for trimming CFRP material for an aerospace partner. We were interested in finding out the tolerances we could achieve with given parameters. As a result of that a parameter optimisation was carried out in order to achieve standards.  The process capability study was captured on a report that went to the customer. The results were shared in a PowerPoint presentation where plans for optimisation were set.    I have train yellow belt delegates in using appropriate metrics for lean and Six Sigma. I provided them with the definitions of cycle time, process capability, tak time, defect rate, defects per unit, defects per million opportunities and they learnt to calculate the Six Sigma score. An important aspect was to translate demand into tak time and plan to identify waste in order to reduce cycle time. For hard evidence of the yellow belt course follow the link below. | | | | | |

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| Competency | | Visual management and control. | | | |
| Performance criteria | | To be able to use appropriate visual management to improve processes and communicate information. | | | |
| Understanding the competency | | Can describe what is meant by visual management and what effects can be expected. | | | |
| Applying the competency | | Has evidence of implementing visual management and/or control in a process. | | | |
| Managing the competency | | Reviews effectiveness of visual management and adjust as appropriate. | | | |
| Training the competency | | Trains others in the appropriate use of visual management and control. | | | |
| Competence statement | | | | | |
| Visual management and control are approaches and techniques that permit one to visually determine the status of a system, factory, or process at a glance and prevent or minimise process variation. Visual controls work to provide a constant focus and attention on the process. This level of attention can help stabilise variation at the improved level of a process. Little training is needed to interpret them.  There are six categories of visual management that allow increasing control of standards, performance and quality:   1. To share of information: making people aware of information for instance on notice boards, traffic lights, posters. 2. To share standards: communicate information about achieving a standard. For example photographs and drawings of parts, layouts, etc. 3. To build in standards: visual management can be used to make it difficult to deviate from standards, examples could be creating Microsoft Word or PowerPoint templates. Visual scheduling boxes (Heijunka) are some other examples. 4. To warn about abnormalities: For example if something is missing, if the power of a battery is low, if production has stopped. Visual boards are an example where it is easy to see if tools are missing. 5. To stop abnormalities once they occur: visual management can be used where an error, abnormality or problem has occurred in order to provide a warning and stop the issue from continuing. 6. To prevent abnormalities altogether: this is similar to poke yoke or error proofing. For example the light in the airplane toilet would not go on until the toilet is locked.   Some areas where visual management and control can be applied are:   * Expose waste in general * 5s control (sign, tape, labels, colour coding, shadow boards, etc.) * Stock control * Control plans * Production / quality / delivery / service metrics * FMEA * Auditing Boards * Spare parts availability * Standard operation procedures / standard work * Production control * Preventive maintenance * Workforce scheduling * Health and Safety * Offices | | | | | |
| Associated evidence | | | | | |
| I have implemented visual control in my area of work:   * To stop abnormalities once they occurred: I put notices in the two doors that gave access to the water jet machine. The notices warned people not to go inside the room if the machine was operating. Additionally, we installed a sensor (Adam and Eve) in the door that stopped the machine if the door was opened. * To share information: I use a board to schedule work orders and write important customer requirements of existing work orders; for example tolerances, part numbers, nozzles being set up, etc. We also have labelled boxes for machine spare parts (orifices, heads and nozzles). * To prevent abnormalities: We set up lines on the floor delimiting the zones where access was not allowed. We had danger signs in places where accidents could occur (e.g. pinching of fingers due to machine moving parts). * To share and communicate standards: we have an image and some parts cut with a waterjet machine that exemplifies the quality of surfaces that we work to, depending the speed of cut. A customer might want a rough quality (1) and a fast turnaround with low cost. By showing the picture we visually make them aware of the cut quality.   Image result for waterjet cut quality  I have trained yellow belts in visual control management during a yellow belt training course I provided for AMRC staff. In the session I gave various examples and asked the delegates to identify examples that were already in place at their workplace and to come up with new ones that could be implemented. For hard evidence of the tools and techniques taught to delegates during the yellow belt sessions follow the link below. | | | | | |

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| Competency | | Workplace optimisation | | | |
| Performance criteria | | To be able to optimise the content and physical layout of a workspace for a process. | | | |
| Understanding the competency | | Can describe the effect on efficiency of physical layout of a process. | | | |
| Applying the competency | | Has evidence of using appropriate techniques to improve workspace, for example, 6s, spaghetti diagrams. | | | |
| Managing the competency | | Reviews effectiveness of workplace optimisation and adjust appropriately. | | | |
| Training the competency | | Trains others in workplace optimisation techniques. | | | |
| Competence statement | | | | | |
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| Associated evidence | | | | | |
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| Competency | | Team based problem solving. | | | |
| Performance criteria | | Maximising the use of team skills in process improvement. | | | |
| Understanding the competency | | Can describe the importance of teams and team-based problem solving in Lean approaches. | | | |
| Applying the competency | | Has evidence of building teams, communicating with teams and using team based approaches in a continual improvement environment. | | | |
| Managing the competency | | Evidence of active team communication and management including analysis of team roles and use of results, for example, Belvin team roles. | | | |
| Training the competency | | Trains others in the importance of team based approaches. | | | |
| Competence statement | | | | | |
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| Associated evidence | | | | | |
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| Competency | | Implementing Lean approaches | | | |
| Performance criteria | | Ensures strategic alignment of activity. | | | |
| Understanding the competency | | Can describe a method to align activity with strategy, e.g. Hoshin Kanri (policy deployment matrix). | | | |
| Applying the competency | | Has evidence of appropriate use of such technique(s). | | | |
| Managing the competency | | Manages changes to organisation to ensure alignment with strategy. | | | |
| Training the competency | | Trains others in the use of appropriate techniques such as policy deployment matrices. | | | |
| Competence statement | | | | | |
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| Associated evidence | | | | | |
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| Competency | | Implementing Lean approaches | | | |
| Performance criteria | | Planning, monitoring and adjusting activity to drive required improvements. | | | |
| Understanding the competency | | Can describe the implementation plan and review process. | | | |
| Applying the competency | | Demonstration of monitoring and review of implementation against plan, definition of any required adjustments to plans and implementation of resulting actions. | | | |
| Managing the competency | |  | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
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| Associated evidence | | | | | |
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| Competency | | Managing productive time. | | | |
| Performance criteria | | Appropriate use of techniques such as OEE and SMED to optimise useful time. | | | |
| Understanding the competency | | Can describe the use of techniques such as SMED and OEE to maximise useful time in processes. | | | |
| Applying the competency | | Has evidence of deploying techniques such as SMED and OEE to maximise useful time in processes. | | | |
| Managing the competency | | Manages processes over the long term to deliver the customer demand using efficiency and effectiveness approaches. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Overall equipment effectiveness (OEE) measures how effectively a manufacturing operation is utilised. It combines process availability, performance and quality in a single metric. OEE is calculated as the actual time the process is producing products (or services) divided by the amount of time that is planned for production. The actual time is based on the time available for production and excludes planned time where production stops (lunch, holidays, shift change, etc.). The performance is the efficiency of the process in minimising its operating time (calculated by dividing the ideal process cycle time by the actual cycle time). Quality is the percent of total output that meets the requirements without need for any repair or rework. | | | | | |
| Associated evidence | | | | | |
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| Competency | | Workload planning | | | |
| Performance criteria | | Planning workload and resource to achieve required targets. | | | |
| Understanding the competency | | Can describe techniques such as heijunka boards to plan activity and required resource. | | | |
| Applying the competency | | Can demonstrate use of workload planning to meet targets. | | | |
| Managing the competency | | Manages processes over the short term to deliver the customer demand using efficiency and effectiveness approaches. | | | |
| Training the competency | |  | | | |
| Competence statement | | | | | |
| Lean includes a set of principles and techniques to achieve improvements in productivity, quality and lead time by eliminating waste. One of the concepts of Lean for planning workload and resources is Heijunka.  Heijunka is a word in Japanese to refer to production levelling or smoothing. It is a technique for reducing Mura (unevenness) which in turn reduces Muda (waste). Heinjunka is used when demand from (internal or external) customers variates. Lean thinking is opposed to large batches in order to level production and minimise costs. Instead Lean produces intermediate goods at a constant rate (small batches, ideally one) so that further processing may also be carried out at a constant and predictable rate. There are two approaches for production levelling:   * Levelling by volume: Levelling the volume of work means having an even base of work from hour to hour. The demand of families of products might fluctuate between small and large volumes. Instead of producing the entire volume ordered by the customer in one run, levelling allows to produce at a calculated long-term average demand and carry a small amount of inventory that meets the variability of the demand. * Levelling by product: Levelling the mix of work means identifying key types of products or services that the process performs and carrying out the work in small batches evenly distributed by type. The focus in this approach is on reducing the time it takes to changeover a process from running one family of products to another family of products; hence achieving smaller batches. Ideally the target is to produce in one piece flow.   The heijunka concept is realised through the application of Kanban cards and heijunka box/board. The heijunka box is a tool that helps schedule work orders. The box is divided into slots each one representing a period of time. The Kanban cards are usually coloured and represent individual upcoming production runs in each period of time (box slot). Heijunka boxes help visualising which types of jobs are in the queue and if there are any problems in production (the cards will not be collected for the next time period). | | | | | |
| Associated evidence | | | | | |
| I have demonstrated the use of workload planning to meet targets, although not by the use of heijunka boards, but with similar visual displays. I have used a whiteboard to schedule work orders in the water jet room. The white board displays information about the current order, future work orders and staff tasks.  Pretty picture here  Another aspect for tackling workload planning was working on the minimisation of setup times on the water jet machine. I tackled this in a few ways:   * Design and manufacture of a water jet probing head. * Design and manufacture of water jet grate * Design and manufacture of modular self-aligning fixture for the production of water jet cut cages | | | | | |

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| Lean and Six Sigma Black Belt Competencies (BS ISO 18404:2015) | | | | | |
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| Competency | | Lean techniques. | | | |
| Performance criteria | | Understands and actively supports Lean implementations with appropriate techniques. | | | |
| Understanding the competency | | Can describe appropriate use of Lean tools, such as current state VSM, future state VSM, 6s, visual management, standard work, etc. | | | |
| Applying the competency | | Demonstration of appropriate use of Lean tools such as current state VSM, future state, VSM, 6s, visual management, standard work, etc. | | | |
| Managing the competency | | Reviews use of Lean tools such as current state VSM, future state VSM, 6s, visual management, standard work, etc. | | | |
| Training the competency | | Trains others to use Lean tools such as current state VSM, future state VSM, 6s, visual management, standard work. | | | |
| Competence statement | | | | | |
| The Lean philosophy includes a set of principles that aim to achieve improvements in productivity, quality and lead-time by defining value as appreciated by the customer, looking at the value stream to identify value and non-value added operations, establish flow in the system, produce only when the upstream operation signals and strive for perfection.  There are a variety of Lean tools that help to achieve this goal:   * Value stream mapping: is a technique for following the production path for a product or service from beginning to end while drawing a visual representation of every process in the material and information flow. In order to create a value stream, the activities that are carried out for the production of a process or service are described at each step, from design to order to raw material to delivery. There are three types of activities in the value stream   - Value added: activities that change the material, modifying its weight, shape or constituents or adding information. I.e. processing.  - Type one muda: activities that create no value but seem unavoidable with current technologies or production assets.  - Type two muda: activities that create no value and are immediately avoidable.   * Future value stream: the ideal value stream map is the ultimate goal of the improvement process. It provides with a vision of what to aim for (strive for perfection). The future state value stream map is an interim state between the current state and the ideal one. This is usually carried out in terms of a short term plan (months). The future value stream map should concentrate on eliminating waste as much as possible, designing a system that flows without delays and obstacles. Implementing pull systems, looking at bottlenecks, reducing cycle time, reducing setups, improving quality performance, change delivery schedules. Typically there will be a need for various future value stream maps with incremental success, approaching to the future vision. * 6s: is a modification of 5s methodology which includes Safety as the 6th S. 5s focuses on organising the workplace and takes its name from five Japanese words:   + Seri (SORT): Identify the items that are essential for getting the job done effectively and efficiently. Make work easier by eliminating obstacles. Segregate unwanted material from the workplace. Define Red-Tag area to place unnecessary items that cannot immediately be disposed of.   + Seiton (SET IN ORDER / STRAIGHTEN/STORE): Put all items I their designated location. Sort and organise all tools, equipment, files, data, material, and resources for quick easy location, and use. Label storage locations, tools and equipment.   + Seiso (SHINE/SWEEPING): Set new standards for cleanliness. Clean and remove all trash. Everything must be clean, tidy, and neatly put in its appropriate place. Keep workplace safe and easy to work.   + Seiketsu (STANDARDISE): Engage the workforce to systematically sort, set in order and clan the workspace. Establish procedures and schedules to ensure consistency implementation. Ensure everybody knows their responsibilities in performing and maintaining the 6s.   + Shitsuke (Sustain): Make 6s part of the work culture, make it a norm. Perform regular audits, train staff, self-discipline.   + - Safety: is the new S added to the methodology. Reviewing every action and each area to ensure that potential hazards are avoided. Aim for zero accidents and near misses. * Visual management: comes from the Japanese term Mieruka and aims to improve the effectiveness of communication and reaction. Some examples are:   + Digital information display called Andons. Displays production rate, the quality defects, and the status of the machines.   + Handwritten data on paper, written by the workers.   + Mark and label locations on the shop floor. Using different colours to mark the location of items. Markings of regulations such as fire and emergency exits.   + Visual management with tools and parts such as shadow boards.   + Machine layouts where you can in which process step the material is. For instance machines organised as a flow shop rather than a workshop. * Standarisation of work. When there is no standard, there is no Kaizen. Standrised work is the baseline for kaizen or continuous improvement, if there are no standards there is no basis for comparison. It would be impossible to objectively assess if there was a difference after a continuous improvement activity. Standarisation of work consists on establishing common ways to carry out activities; precise work sequences in which an operator performs tasks within takt time, tools and techniques needed, etc. Standarisation of work improves employees morale (work is fair), health and safety, eliminates waste, improves quality. | | | | | |
| Associated evidence | | | | | |
| I have used different tools of Lean sigma  Value stream maps. I used VSM to distinguish between value added and non-value added tasks. It allowed me to picture a future VSM where setups and inspections can be minimised by improving procedures and quality.  6s is one of the Lean techniques that has made a big improvement in the water jet working area. We implemented it as part of the “Green Belt” project in the water jet area. Prior to 6s the area was untidy, there was a lot of “clutter” lying around, the tools were everywhere and we used to spend time looking for things. After 6s the area was completely organised, tools were marked and put in place. We had a rota to show responsibilities for sustaining the 6s results.    Visual management. I have established visual management techniques while working at the AMRC, in the form of machine layouts and visual information about Health and Safety. This helped in organised the workshop, knowing where the raw materials, the finished parts had to be stored. It also improved health and safety as the area for visitors was clearly marked, fire exits indicated.  Standarisation. I have produced standard procedures for working on the water jet machine. An example is a routine for calibration of the nozzle length. We were having problems of inconsistent calibration as the operators and research assistant had their own method. In a team meeting we discussed the calibration procedure and came up with a standard. This improved traceability and made it possible for further improvements.    I trained Lean six sigma tools as part of an internal Yellow Belt course I delivered at the AMRC. For hard evidence see link below. | | | | | |

Table Yellow Belt Course Tools



