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# A STRATEGY FOR ACHIEVING MANUFACTURING STATISTICAL PROCESS CONTROL WITHIN A HIGHLY COMPLEX AEROSPACE ENVIRONMENT

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## ABSTRACT

This paper presents a strategy to achieve process control and overcome the previously mentioned industry constraints by changing the company focus to the process as opposed to the product. The strategy strives to achieve process control by identifying and controlling the process parameters that influence process capability followed by the implementation of a process control framework that marries statistical methods with lean business process and change management principles. The reliability of the proposed strategy is appraised using case study methodology in a state of the art manufacturing facility on Multi-axis CNC machine tools.

**Keywords**: Process Control, Process Capability, Multi-axis Machine tools

## 1 INTRODUCTION

The world is rapidly evolving with new technologies and innovations that are affecting manufacturing. We are in a time of increased miniaturisation, increasing fuel efficiency and higher levels of integration. All these elements combined create a climate that calls for a sustained supply of high precision components (Brinksmeier, 2010).

For these reasons, quality conformance and control are crucial characteristics in the aerospace and defence industry. Additionally, high value materials and the advanced manufacturing techniques lead to components of extremely high production value. Therefore additional emphasis is paid to the avoidance of scrap through increased quality conformance by achieving process control. The advantages for aerospace and defence manufacturing companies adopting a dedicated stance towards high levels of quality conformance and control are many, for example;

- A quicker assembly and fitting process
- Increased interchangebility of parts
- Improved energy efficiency in assembled products (engines, generators)
- Improved product performance

The aerospace and Defence industry is a mass user of multi-axis CNC machine tools because of the scale and complexity of components that the industry requires. However, within this unique manufacturing environment it is very difficult to achieve manufacturing “total process control” from the traditional part conformance perspective. Finite batch orders, typically below one-hundred units, leads to a slow but steady throughput of large components featuring multiple complex features and intricate datum systems. They usually require multiple machining stages in different orientations and the flexible nature of modern manufacturing systems often dictate different machines for the separate stages (Nau, 2012). As a result, determining the "root cause" of conformance issues or the key influencers of variability will be difficult to achieve. In this respect, when compared to the automotive industry, the aerospace and defence industry is at an obvious disadvantage. High volumes, typically in the excess of the tens of thousands, create a lot of "opportunity" for process engineers to learn, iterate and fine-tune to perfect the manufacturing process. Furthermore high volumes justify a dedicated manufacturing line for the manufacture of specific components, whereas the low volumes of the aerospace industry calls for a "flexible manufacturing" approach where multiple components can be made on the same line or in the same production cell, and the manufacturing system can quickly reconfigure to accommodate a varying demand (Lauzon, 1997).

There are also cultural elements that contribute to the difficulty in achieving process control. Variability reduction, process control and other initiatives that involve elements of change management are particularly difficult to establish in an aerospace and defence manufacturing setting. Love(1995) suggests that there are many reason for this, but typically because companies are unable to quantify the cost and benefits of quality and variability reduction efforts, and also quantify the benefits of process improvement efforts (Love, 1995).

Research by Ho (2008) into the success of manufacturing companies incorporating variability reduction programs such as Six Sigma found that there were five success factors in its implementation, namely:

- Top management commitment and participation.
- Formulating projects and programs based on customer demand.
- The use of data analysis with data that is easily obtainable.
- Investment of essential resource.
- Incentive/reward systems.

It is also stressed that without a strong project management competence within the organisation there is a strong possibility that the in-corporation of a variability reduction strategy or program will fail (Antony, 2002) (Kwak, 2006).

Hence a new strategy is required to achieve process control that is underpinned by fundamental statistical process control and lean principles, whilst tailored to CNC Multi-axis Machining Manufacturing environments. The approach also needs to integrate elements of change management to overcome cultural factors that often suppress process improvement initiatives. The proposed strategy consists of three elements as shown in Figure 1. The first element provides the theoretical foundation that the other two are built upon. The second provides the principles and practice that form the framework. The third provides the deployment process that guides the business in the establishment of the process control framework and also on the journey towards process control.

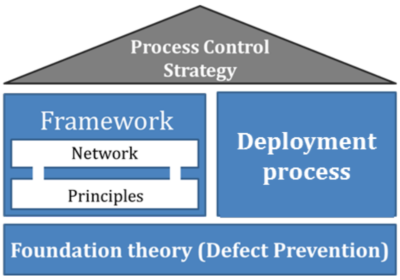


Figure 1: The proposed process control strategy

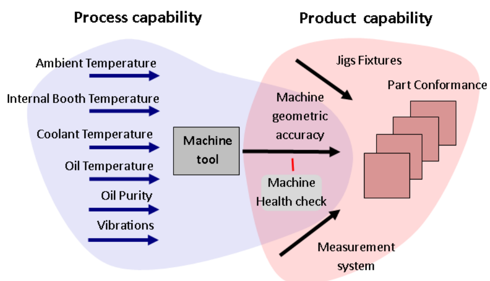


Figure 2: Process parameters

## 2 ELEMENT ONE - CONTROLLING PROCESS PARAMETERS

As discussed earlier in this paper, achieving total process control is extremely difficult to accomplish in manufacturing lines consisting of multi-axis machine tools. A solution to this problem is proposed by refocusing control efforts away from the "product" and concentrating on to the "process". If we successfully exert enough control over all the stages, sub-processes and parameters of a manufacturing system, this should enable confidence that the system output will be within acceptable limits (Crosby, 2006).

However, firstly the terminology needs to be defined. Within the aerospace and defence industry the term “process control” or “process capability” is used widely and is commonly used to reflect an entire manufacturing lines ability to produce a conforming output unit. This is neither right nor wrong as definitions vary between authors and academics. However, for the purpose of this paper and the proposed framework:

- Product Control/Capability is the ability of the manufacturing process to produce a conforming component.
- Process Control/Capability is an ability of a process to produce an output within acceptable limits.

Adopting these definitions, a CNC Machine tool is now recognised as a process. Therefore, from a machine tool perspective, process capability can be defined as the machines ability to consistently operate with a geometric accuracy within predefined acceptable limits.

Embracing this change in perspective, it becomes clear that by improving and controlling individual “Processes” within a manufacturing line, then by consequence we will improve the product capability. In order to control a process, we must control the process parameters. As illustrated in Figure 2, process parameters are input factors that influence the output of the process. Machine geometric accuracy is one parameter that contributes to “product capability”, and in-turn, geometric accuracy is controlled via input parameters to the CNC machine tool. This strategy is commonly referred to as defect prevention because of the specific effort to eliminate process based defects.

Typical multi-axis CNC machine tool process parameters include coolant temperature, warm-up time, vibrations, ambient temperature and oil purity. A variety of condition monitoring techniques can be used to continually assess and control these process parameters, such as thermocouples, humidity probes and data loggers. CNC machine tool “health checks” can be used to determine the error of individual axis movements. The “Renishaw ball” is a linear variable differential transformer (LVDT) that independently measures error in movement in the XY, YZ and XZ planes.

This approach enables this strategy to overcome the constraints of low volume part throughput. Both the machining process parameters and the machine tool geometric accuracies can be monitored and controlled independently of component throughput. Using condition monitoring techniques we can monitor and collect data from the process parameters at a frequency of our own discretion. This can provides process engineers with sufficient data to gain understanding and thus exert influence over the behaviour of the process, striving towards process control..

## 3 ELEMENT TWO - THE PROCESS CONTROL FRAMEWORK

The process control framework is an element of the manufacturing Failure Mode Avoidance Strategy. Its aim is to provide the using manufacturing company with a clear strategy that enables efficient and effective process control for processes inclusive of multi axis machine tools. It marries robust statistical technique, quality management and assurance requirements, lean and reliable business process design and change management principles. The strategy is underpinned by a collection of principles and a network that maps the framework on to an organisational manufacturing process.

This Framework was developed, trailed and demonstrated at BAE Systems (Military Air and information), in a state of the art hard metal CNC machining facility housing multiple CNC Machining Centres and a flexible manufacturing system.

The governing principles form the foundation of the framework and can be sub-divided in to two categories, namely Cultural and Technical.

***Cultural***

- **Training and terminology**: Ensuring all terms and definitions are aligned and all employees in the manufacturing facility having a common understanding between product and process control/capability.
- **Management Driven**: Senior management owns the process and is visibly involved in its management.
- **Defined roles and responsibilities**: Governed by senior management and enforced via operations, roles and responsibilities are consistent defined and visible.

- **Visual management**: Visually displaying performance, strategy and current status help employees at all levels understand how there labour contributes to the wider strategy.
- **Role Based Training**: With regard to the framework, individuals are trained in the skills and techniques that they require to complete their respective tasks.

***Technical***

- **Embodiment of Statistical Process control**: Ensuring that statistical process control and Six Sigma principles are at the centre of the construction and use of the framework.
- **Iterate and refine controls**: Driven by data, iterate and refine the controls of the framework to strike a balance between the extremities of being sensitive enough to capture issues and errors, and being too sensitive in that the framework triggers costly "false alarms". This principle is particularly important for manufacturing engineers when governing the sensitivity of control limits.
- **Software solutions**: The framework provides a template for application. Software solutions are the best way to approach the application of the framework in to a manufacturing facility.
- **Smart perspective interface design**: Activities where a stakeholder is interacting with the framework are designed from the perspective and requirements of the stakeholder.
- **Central issue's register**: One central issues register that is used as a depository for all process parameter and geometric accuracy issues. The register is used to store, manage and organise, allocate and control process issues and actions.
- **Tailoring**: The principles and network should be used in a guidance capacity as opposed to a manual. Each business or manufacturing facility, have unique traits and ways of working. In order for this strategy to be effective it is crucial that the organisation tailor the tools and technique to meet their own current need.

The network uses these principles and provides the skeleton structure which enables the framework to be integrated in to a typical multi-axis CNC machining facility. The network is illustrated in Figure 5. Following defect prevention theory (Handfield, 2008), the network is a tailored design aimed to provide the most effective, lean and efficient method for measuring and controlling process parameters.

A prototype was developed as a Microsoft VBA database although other software solutions can easily be pursued. A paper based system can be used, however software solutions provides the most efficient and effective method of applying the framework.

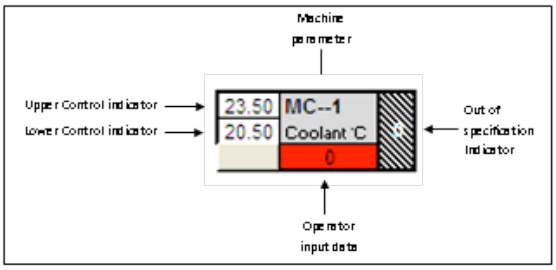


Figure 3: Operator data input box

Figure 4: Interface Layout

The framework encourages human interaction within the process with regard to the measurement, collection and assessment of data as opposed to total automation. This is to ensure that issues are escalated timely and there is increased ownership of the process. The smart user interface design principle should be adopted to ensure that the collection and assessment of data does not become arduous. For example, in trialling this strategy at BAE systems, a simplified "box template" method was integrated into the software solution, see Figure 3. The operator simply enters the value then clicks the save button and the system will then indicate to the operator if the unit of data has exceeded or fallen below control or specification limits. The interface was designed to replicate the format of the shop floor so the operator would benefit from the familiarity of the layout making the software less intimidating and more user friendly, see Figure 4. The data is also saved and stored for later engineering analysis. This method also aligns with the role based training principle, recognising that the shop floor operator is only required to recognise if the value is within acceptable limits, whereas the manufacturing engineer is required conducting more detailed statistical analysis.

Guided by the visual management principle the capability dashboard summarises the data measured and collected and provides an overview of the facility performance in terms of variability of process parameters. This will motivate the shop floor in terms of collecting data because they can see the purpose and outcome of their efforts. The senior management would also use this as a management tool to monitor and control the facility from a high-level.

The network enables clarity of roles and responsibilities and ease of access for the each user. For example the network provides the manufacturing engineer (as illustrated in Figure 5) with the ability to monitor, analyse and exert control of over multiple process parameters from one central hub and then summarise performance to senior management who have the responsibility and authority to govern and manage the entire process.

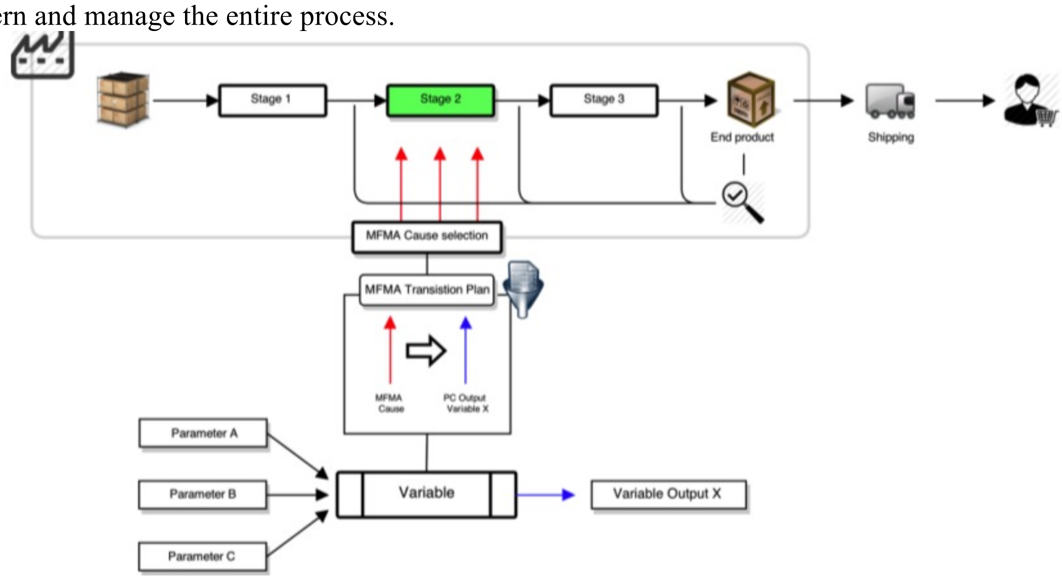


Figure 5: Process control network

The central issue's register is the anchor the binds together the entire network and facilitates process control by managing and controlling corrective actions that are fed from the CNC process parameters. Managed by operations working under the authority of senior management, the central issue's register completes the control loop enabling the reduction of variation in process parameters.

## 4 ELEMENT THREE - THE DEPLOYMENT PROCESS

Process improvement and variability reduction initiatives and programs often fail to integrate into traditional manufacturing operations for many reasons; one of the main suspected reasons is that whilst these programs are strong in academic and strategic theory, many of the variability reduction efforts lack robust project management technique. As a consequence the results realised are often apart from what was expected. The deployment process establishes detailed controls throughout the process of integrating the framework into the organisation to ensure that process control is achieved manufacturing (Neuendorf, 2004).

There are four main stages to the deployment process. The pre-process stage is primarily for the setting up of the mechanisms that enables successful project management. Tasks include the allocation roles and responsibilities, creating a high-level project plan for the current and subsequent stages and clarifying the objectives. The aim of the first stage is to identify priorities and plan the control of the process parameters. It involves workshops with the process subject matter experts. Methods of measurement for each process parameter are identified and plans are put in place to install them. Stage two is the application of the framework in to the manufacturing facility according to the project plan created in stage one. As already stated the framework should not be holistically applied, rather tailored to the using organisation's specific need to ensure that the most can be gained from it. Stage three is enabled when the framework is in place and the measurement of the process parameters behaviour/performance is enabled. Therefore a baseline for performance can be determined. This baseline can then be used to set quantitative objectives for process improvement. Progress against these objectives can be monitored via the framework controls. The deployment progresses into stage four once a satisfactory outcome of stage 3 is reached, i.e. the objectives have been met or the chairman of the process is satisfied with the improvements made.

## 5 DISCUSSION AND CONCLUSIONS

The framework described in this paper was deployed in a flexible manufacturing facility which houses multiple multi-axis machine tools. The facility produces hard metal components of high value and complexity to the aerospace and defence industry. The deployment of the framework was mostly successful. The pre-process stage was very effective in overcoming the project management woes that commonly hinder variability reduction efforts in manufacturing facilities. Aspects such as the pre-project purposefully being separate from the deployment stages provides flexibility in ensuring that the deployment is scoped and tailored properly to meet the current needs of the facility. Rules such as the project high level plan and start date not being detailed until the “end product” is defined were effective in ensuring that a robust project management infrastructure was in place before the deployment began. Generic detailed high level deployment plans enabled teams to develop a bird’s eye perspective of the whole implementation and raised awareness of progress towards a destination, rather than the aimless journey that plagues many process improvement efforts.

The visibility of the process performance and parameter performance through the central capability dashboard also provided vital stimuli for cultural change. Once involved teams could visibly see the outcome of the fruits of their labour, then this eased much of the potential resistance to the implementation of the strategy and system. Technically the system was also effective. It enabled an overview of performance for all process parameters on one summary dashboard providing Cpk values for high level management. It also provided greater detail for manufacturing engineers to scrutinise and exert control over the quality parameters.

In conclusion, the system’s performance in the provision of a framework that enables process control and realisation of capability is satisfactory. The strategy has proved to have the ability to both react quickly to process errors and ensure escalation, and also drive strategic change through the logging of process errors. The strategy plays a major role in driving cultural change in the using organisation. However further time and data is required to fully realise the benefits and value of the strategy to this unique manufacturing environment.

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