ABSTRACT

SERVICE QUALITY ASSESSMENT AND IMPROVEMENT METHODS AND TOOLS

by
Kevin M. Moriarty

The nucleus of this research concept and system is being applied to turret lathe and milling machine Computer Numerical Control (CNC) tool systems. The research has a generic application to the service of broad array of sophisticated computer controlled / integrated machines, devices / equipment such as industrial robotics, medical equipment, surgical robots, and similar types of engineered system. Quality design review for quality service systems is a unique concept. Standard product service systems are qualitative and subjective in nature. The quantitative system identifies Key Predictive Attributes (KPAs) and applies quantitative methods to these attributes to develop a systematic process of analyzing and monitoring the system. This research is reviewing the specific projection of service outcomes for Machine tool CNC machining centers (Lathes and Milling Machines) for which significant data has still been available for research conducted during the covid-19 pandemic. The specific Key Predictive Attributes are the attributes to be utilized in the newly created modular function in this research. This is a unique application of the creation of diverse service factors. The examples of these KPA factors are, performance utility “Experience Performance Factor”, an ingenious “Delta Sum” forecasting technique, a “service life cycle” analysis factor, and the creation of a “Service Risk Factor”.

The KPA factor performance utility “experience performance factor” for this application (utilizing a unique percentage specifically developed for this application). The

forecasting factor of delta sum forecasting technique uniquely created for this modular function. The service life cycle analysis method for this equipment has been created to add this as a KPA for the function. The service risk factor utilizes an equation to assign a quantitative value to risk assessment of equipment interruption and down time as well. These are all applied to the process through Quantified Service Quality.

This project is unique in that currently there is no system which utilizes methods or tools which proactively gather, analyze, assess, and project outcomes of equipment "Down Time" of the Service Quality process.

What makes this research unique additionally is the system is pre-service and not post service reporting of actual down time of the equipment. This research is much more than pro-forma estimates of service outcomes. Another unique aspect of this method is that it establishes tangible tolerances to assess the performance of the Design Review and Service Quality process and does not just rely on subjective nominal values. Mathematical Upper Control Limits (UCL) and Lower Control Limits (LCL) are programmatically developed based upon the system data. This system tool has developed programming algorithms which successfully propel the current process from a subjective qualitative process to become a robust quantitative projection tool. The emphasis of this research is the development of a quality index through the creation of the Moriarty/Ranky Transform approach.

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by
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TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

TABLE OF CONTENTS CONTINUED

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF SYMBOLS

©	Copyright
∫	Integration
η	Experience performance Days
®	Registered
≈	Approximately
γ	Learning days
#	Number Sign

LIST OF DEFINITIONS

Accuracy	Measurement to real value of process variable measured.
Effective array	The part of the process (usually upper 80 percent) that machine has appropriate accuracy.
KPA	The key predictive attribute of the process
Standard	The typical, accepted value of the specific process
PCA	Principal components analysis
CNC	Computer Numerical Control
PQSS	Predictive Quantitative Service System
QSQ	Quantitative Service Quality
MCDM	Multi-Criteria Decision Making
MINL	Mixed Integer Non-Linear
MIL	Mixed Integer Linear
AHP	Analytical Hierarchy Process
EOL	End of Life
PMBOK	Project Management Body of Knowledge
QSI	Quantified Service Index

CHAPTER 1
INTRODUCTION

1.1 Objective

Chapter 1 reviews and describes in general terms current offerings and identify their common limitations (e.g., not real time and not smart). Currently organizations address Quality Service Systems through post process reporting and accounting. The service outcome projections currently in practice are heuristic (pro-forma) methods based upon these post process accounting methods. This has several limitations; primarily it is out of date (past) information, i.e., end of month reporting which cannot be acted upon in real time. Many researcher and industries participate in and have developed several varieties of product maintenance programs; repair, preventive, predictive maintenance systems are ubiquitous throughout industry. This research and system take all these systems to a different level. This system sits on top of these systems to predict the expected outcome / performance of the planned maintenance service.

This dissertation has developed a new predictive tool which creates a composite predicted Quality Index Score for an upcoming service which is ("Smart" i.e. dynamic and evolving) It also provides a multidimensional index revealing the key drivers of the predicted composite Quality Index Score.

The dissertation is organized to explain the results of this research and the results of this research create a Quality Index that predicts the Product Quality Service effectiveness (predictive and multi-dimensional) of the past experiences.

Current methods have several limitations in that the organization doesn't get to respond to this information until the reports are generated and presented.

Service system quality design reviews should be performed during different stages of the service process. This results in waste and cost reduction, as well as minimizing product service delays.

A superior quality service system design review, when successful, activates system process improvements throughout the system. This then resulted in an effective quality service product introduction. An example of a critical service area is health care emergency services (e.g., police, medical responders, security). The methods and tools developed, establish a high-quality service system for; engineering, management, and associate / operator.

This system helps facilitate critical thinking, agility, creativity, and awareness of the importance of a product quality service system for enterprise design and a well- equipped, organized and educated workforce.

"To design and optimize production systems as well as to choose the optimal product matches, product analysis methods are needed. Indeed, most of the known methods aim to analyze a product or one product family on the physical level or different product families". [Zou, Brax, Rajala, 2018].

Product Service Systems (PSS) are inherently complex. Much research has gone into the study of attempting to understand these complexities. [Wuesta, Wellsandtb, 2016]. "The study of the impact of PSS emphasizes the importance of having life cycle support tailored to a time scale associated with traditional products to a constant delivery of customer satisfaction and value". Previous studies have focused on “traditional three phases, Beginning of Life (BOL), Middle of Life (MOL), and End of Life (EOL) model” assessing the product lifecycle from a technical view. [Wuesta, Wellsandtb, 2016]

Quality Service Systems involve a growing number of components, sub-systems, activities, and components. The service provider has to coordinate many aspects of system requirements to ensure they technically and dependably work with other systems as well. The principal factor over all is to minimize the impact to the operation causing delays and down-time. “In manufacturing firms, system implementation typically raises the number of service components, stakeholders and interactions included in the system [Sakao, Song, Matschewsky, 2017], [Brax, Visintin, 2017], [Eloranta, Turunen, 2016]. Several stakeholders of the quality and service process participate within the system at different steps of the Quality Service process, i.e., “the focal company, its suppliers, and other organizations or individuals, end users” of the product, [Brax, Visintin, 2017].

(Note: every quality product must contain a quality service constituent as well.)

1.2 Research Question/Hypothesis

The question associated with this research project is.

The results of this research have been the study of impacts service down time has on CNC operations and the development of a unique quantitative tool, which does not exist in the today introduced and utilized for a robust “Product Quality Service System” that do not exist in the market today.

1.3 Purpose of the Project

This goal for this project has created a quantitative system (PQSS), through a unique (M/R T, Moriarty/Ranky Transform) to be utilized within service organizations to assess and improve the product quality service, which is sufficiently diverse and robust to be functional across several platforms and industries. This is a weighted composite equation and index, as a result, which can handle tolerances (since service quality should be modeled as a dynamic system).

1.4 Statement of the Problem

Currently within industry there does not exist a fully functioning, robust quantitative "Product Service Quality System" which proactively assesses, predicts, and improves Service Quality utilizing a systematic approach. This research has evaluated and validated performance requirements against the outcomes of the service activities in order to discover problems before the use of additional key resources and reorganize resources as a result of the service tool analysis to proactively improve the overall service process. The concentration of this work is the establishment of a quantitative tool to be utilized across a broad range of businesses and industries that moves the design review and product quality service process from a reporting tool to a proactive, predictive system to ensure continual improvement of the process. The KPAs assessment establishes active upper and lower tolerances, not just a discrete nominal figure. This tool proactively enhances the process before the performance of the design review or the product quality service process and reports the results. This process today is always a post assessment analysis of past practice. The key to this procedure is that it establishes the parameters to be met before the design or service. The desirable results with allowable statically developed tolerances of the KPAs are established before the performance of the task.

Examples of KPAs.

1. Reliability of the service
2. Responsiveness of the service
3. Competence of the service providers
4. Access to the desired service
5. Courtesy and kindness of those who provide the service
6. Communication skills of service providers
7. Credibility of the service providers

Customer response based Key Performance Attributes:

1. Was the first contact successful
2. Number of Service visits
3. Warranty
4. Non-Warranty
5. Repair requirements
6. Parts
7. Labor only
8. Number of Repeat Visits
9. Same issue
10. New (different) issue
11. Service visit within expected (customer) time frame
12. Service provided on time
13. Service performed to customer satisfaction
14. Service provided within allocated time, (within budget)

1.5 Methodology

This is an original approach because there is no evidence that a random generation of such data is now in use, and the direct data input does not exist because this system is not available academically or commercially yet.

The focus of the project includes the following service system design dimensions:

i) Three studies are incorporated in this research project:
a) random generation for initial stage of simulation testing simulation study
b) direct data input from service technician's real data collection as services are provided actual data study
c) final results study

ii) An acceptable tolerance range / function for each KPA is established through statistical methods of acceptable quality limits (AQL) and process control figures of the upper and lower control limits as they relate to the statistical standard deviations of the data.

iii) System validation is conducted through utilizing the system simulation tool developed in Microsoft excel and the mathematical methods built into the system; (risk assessment, forecasting, probability, regression analysis and experience performance computational analysis) .

iv) The system / research calculates; expected & actual service time, performance (satisfaction) cost of service call, travel time vs service work time, and on time delivery (arrival time/completion time) vs expectations, using the analytical method defined in this document.

1.6 Quantitative Tools

Here are some of the fundamental methods and techniques utilized to create the M/R T transform.

The quantitative tools that are incorporated into this system generate a PQSS Score or Index number through this unique, Transform Model known as (M/R T), created exclusively for this system:

Experience performance method. The performance of service technicians and service providers is highly contingent upon the experience performance process. Peak quality service and the cost effectiveness of the process is not achieved until the service provider has fully developed the knowledge and skills of the particular service being provided. This function is a critical measure and a Key Performance Indicator of this predictive quality service tool. Some significant aspects of the human component of the service industry are hinged upon the tenure and longevity of the employees as well as the level of their expertise. The time it takes for a service provider to achieve the full “Steady State” performance value is crucial to quality service.

This mathematical tool is an approach to service systems used to calculate the projected results of the service task(s)

Experience performance calculation:

Y_x = Steady State output (full efficiency), $Y_x = aX^b$

a = initial time for output

X = number of units produced to reach steady state.

b = the learning index or coefficient, which uses a different calculation:

log (L [experience performance percentage]) ÷ log 2.

Where, a min percentage (α), a max percentage (β), and a most likely percentage (χ) are utilized to generate the Experience performance percentage (L).

Therefore, L = $(\alpha + 4\chi + \beta) / 6$

So (b) is a unique parameter for this research generated by the system inputs creating a modified measure of experience performance percentage, which is considered a more appropriate value for this application. This is a different method of creating an accepted value of experience performance theory unique to this research used within the M/R T model today.

A sample result, given; $\alpha = 98\%$, $\chi = 85\%$, $\beta = 65\%$

L $= [\ 0.98 + 4(0.85) + 0.65\ ] / 6 = 0.8383,$

= log L ÷ log 2 = -0.07658 / 0.30103 = - 0.2544.

Maximum likelihood; "Maximum Likelihood Estimation (MLE): The MLE is a different method for estimating two parameters of η and β. The outcome of the estimated parameters is applied in the prognostic modelling. The MLE is commonly utilized due to its numerical accuracy" [Abernethy, 2006], [Bechhoefer, Schlanbusch, Waag, 2015]. "The likelihood function is used to estimate the two parameters required for the following Equation. Consider n random samples with F(t,η,β)". [Okoh, Roy, Mehnen, 2014]

Service Life Analysis: This service life analysis is an age failure relationship. The Weibull analysis is typically used for life cycle failure analysis commonly known as "Reliability Life Data Analysis".

$$f(t) = \frac{\beta}{n}\left(\frac{t - \gamma}{n}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{n}\right)^{\beta}} \quad (2.1)$$

Estimation & Forecasting Methods.

Evaluation of Forecasting Model utilizing an algorithm which incorporates an amalgamation of the following techniques to create a hybrid solution:

Simple Moving Average (SMA)

Unique Delta Sum Method (UDSM). This created delta sum forecasting method introduces the use of the delta "Δ", or variance between the forecast and the actual values and applies 50% of that result to additional smooth out the projected forecast numeric result.

Utilizing the required λ between 0 and 1 ($0 < \lambda < 1$), specific alpha factors utilized within this simulation are (0.4, 0.6 & 0.8).

F_{ex} = (1- λ)(Last Actual Value) + 0.5 $\Delta + \lambda$(Last Forecast)

Forecasting Error analysis, a fusion of these methods:

Mean Absolute Deviation - MAD

Mean Absolute Percentage Error – MAPE

Predictive vs Diagnostic Maintenance.

Predictive is when there is nothing wrong yet, but internal components are wearing which may result in a failure. Diagnosis is when there is something wrong and the service technician must determine the problem and/or failure. [Wiseman, 2015].

Statistical analysis.

These are utilized to create the upper and lower control limits of the KPA tolerances.

Probability Models.

This mathematical process is utilized to develop the expected process outcome success (rates). This is unique to Design Review and Service Quality Systems because currently there is no application of a probabilistic approach to this process in use today.

1.7 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is an effective way to apply quantitative methods to the analysis of CNC service component data. PCA is widely used in all forms of analysis, from computer graphics to social research, as it is a simple, non-parametric method of extracting relevant information from large amounts of data. PCA is useful when someone has collected many measurements of observed variables and wants to develop a smaller number of artificial variables (called principal components) that explain most of the differences in the observed variables. The quantity of variables examined in the analysis matches the quantity of components extracted in the principal component analysis. This means that a data set of seven variables generates seven components.

In most analyzes, however, only the first components have a large variance, so only these first components are retained, explained, and used in the subsequent analysis, and the remaining other components have little variance, [Hosseini, Owlia, 2016]. These components can be grouped or discarded. Similarly, PCA is viewed as a variable reduction program, making it an effective statistical method that can be used to reduce complex data sets to lower dimensions, thereby revealing knowledge or patterns that are normally hidden in the data. In this case, PCA is useful when someone is collecting a large data set with a large number of variables and believes that the data set has some redundancy.

“In this case, redundancy means that certain variables are related to each other, possibly because they measure the same entity” [Hosseini, et al., 2016]. However, this redundancy can be reduced to a few main components that account for most of the differences in the observed variables [Holland, 2008].

“The following is the general form of the math formula that calculates the score of the first component extracted in the principal component analysis” [O'Rourke, Hatcher, 2013].

An example of the scoring method of the primary component PC1 of component 1 (component number one reviewed), there is a coefficient of regression (b1p or weight) of the examined element (p) which is then used to create the primary component 1 value X, and then Xp is the value assigned to the reviewed variable p. This then calculates the first principal component so that it takes into account the greatest possible variance in the data set.

In a typical scenario this means that number one element relates to at least some of the reviewed variables. It can be related to many. Of course, you can make the variance of Y1 as large as possible by choosing larger values for the weights b11, b12, b1p. To avoid this situation, the calculation of the weights must be restricted to the case where the sum of their squares equals one, i.e., H.

There are two key features associated with the next subsequent component obtained:

First, it explains the maximum variance of the first component in the data set and also correlates with some observed variables that are not strongly correlated with the first component.

Second, the second component is not connected to the first component. When the quantitative relationship between items 1 and 2 are calculated, this value is normally zero, [Holland, S, 2008]. 3 The remaining items reviewed in the analysis have the same two qualities. The primary component makes up the greatest variance in the observed variables, and these remaining variables are not accounted for by the previous components and are not related to any of the previous components.

“Principal Component Analysis” is applied through a method where each new element displays a shrinking variance that is continually reducing (this is why the first component is the only one typically maintained). When the analysis is completed, the components obtained show different degrees and observations. The variables are correlated, but completely uncorrelated with one another [Sharma, 1996], [Hair, Money, Samouel, Page, 2007]. The calculation method for the second main component corresponds to the formula. As explained previously, only the beginning select components contribute significantly to the variances. Therefore, these are the only these are the components that are only maintained, accounted for, and applied in the breakdown of the quantitative method of evaluation. All other elements of this analysis are insignificant to the overall variances. These can either be combined or removed and rejected from the analysis.

Also, PCA is considered as a variable reduction procedure, which makes it an efficient statistical method in reducing a complex data set to a lower dimension thus revealing knowledge or patterns that are often hidden in the data. In this case, PCA is useful when someone has collected a large dataset which contains large numbers of variables and believes that there is some redundancy in this dataset.

For this situation, some of the values are related and associated with each other when they are redundant. This can be caused when these variables are assessing the same the same element. However, the duplication of elements is decreased to a minimal number of principal components which make up most of the variance in the reviewed variables [Holland, 2008]. There is a general mathematical formula that computes the value of the primary component as obtained from a “Principal Component Analysis” method [O'Rourke, Hatcher, 2013]. The value assigned to principal component 1 (the first item reviewed) is identified as PC1, and b1p is the coefficient of regression (or weight factor) for the reviewed variable p, as used in creating primary component 1, while Xp is the values of evaluated variable p. When the primary element is computed it will have the highest variance in the data set. Under typical conditions, this means that the primary component will be related to and associated with a few of the reviewed variables but could also be associated with several. Of course, one could make the variance of Y1 as large as possible by choosing large values for the weights b11, b12, b1p. To avoid this, weights are calculated with the constraint that their sum of squares equals 1.

The second component reviewed has two key attributes: it is the second highest variance in the data set, not including the first component, and it is also related to and/or associated with other reviewed variables not closely related to or associated with the primary item reviewed. The next component is not related to or associated with the initial primary part.

Specifically, if you want to calculate the relationship between two components A and B, the correlation value will be zero [Holland, 2008]. The remaining elements reviewed in the analysis then have the same characteristics; one they both have a maximum amount of variance in the examined elements which are not included in previous elements and is not related to or associated with the previous elements. “Principal Component Analysis” is accomplished through the process and method described here. Every element contributes to an ever-decreasing variance (for this reason the beginning few components are typically the only values maintained and evaluated in the analysis). Once the analysis is finished, the remaining components demonstrate different amounts of correlation with the variables examined. These elements are not related to or associated with each other [Sharma, 1996], [Hair et al., 2007]. The next element can be calculated in the same manner.

CHAPTER 2

CNC SERVICE QUALITY RISK ASSESSMENT

Uncertainties related to machine down time can have a very high cost to modern manufacturing organizations in the form of, productivity losses, product lead times, and poor-quality low product yields. Recurrent CNC machine malfunctions can result in major economic losses, poor customer service, and loss of business reputation. Many examples of the occurrences of down time disruption due to machine failure and or maintenance issues are prolific throughout modern organizations. These instances cause process volatility, disruptions to productivity, digital incidents throughout the Industrial Internet of things (known as IIoT) process, which are all contributors to CNC machine down time risk. While “just-in-time” and lean concepts may benefit the organization in general, these concepts may contribute to risk during process stoppages. The identification, assessment and management of risk is the focus of this section of research. A combination of modern methods and techniques are presented in this research to successfully address and manage the consequences of risks associated with CNC machine down time.

2.1 Basic Understanding of CNC Risk

Due to potential disruptions to process flow, many scholars have developed models and methods for managing risk. This research is primarily demonstrating a unique application of Analytical Hierarchy Process (AHP) Risk Assessment method to CNC service maintenance utilizing approaches used in other industries, but never applied to the CNC service industry. The area of supply chain risk and management has been responsible for a great deal of work subject material. These methods are reviewed and compared to the application of AHP in the CNC service maintenance field. Supply chain risk management known as (SCRM) utilizes a phased systematic method of identifying, assessing, prioritizing, monitoring, and mitigating potential disruptions to the supply chain and this method can also be applied and utilized in the CNC machine tool space in order to reduce the negative impact and disruptions in production operations [Aqlan, Lam, 2016]. The likely risks and factors in manufacturing can be determined in a risk identification phase followed by the prioritization of risks through estimating the likelihood of occurrence and impact on the manufacturing process in the risk assessment phase. In an attempt to mitigate risk, the most appropriate mitigation strategy for risk or combinations of risks can be identified in a mitigation phase [Khan, Burnes. 2007].

Over time, there have been a wide variety of debates about whether risk is a subjective or objective occurrence, both have their negative and positive consequences. The relationship between risk and uncertainty have raised a wide range of debates. The subjective view supports a belief that risk is determined by the views of the interested party and participants involved (political, industrial community or the general public as well as other views). There are others who consider risk objectively defined based upon quantitative data and analysis. While most agree with the outcomes, risks are usually associated with undesirable effects (i.e., losses). While incidents may be relatively uncommon, researchers focus less on the potential positive effects (i.e., benefits) in uncertain situations. Regarding the relationship between risk and uncertainty, one may consider risk as the expected outcome of an uncertain event, while a different perspective may view risk as the uncertainty of events and possible outcomes. This model views the knowledge of decision makers for the entire supply chain, from complete security to fundamental uncertainty, [Vilko, Ritala, Edelmann. 2014].

There are different stages of increasing uncertainty between the two. The closest thing to complete certainty is a situation that is the basis of a typical SCRM: in this case, the supply chain structure is fully known, and the possibility and impact of future events are known based on objective probabilities, [Baryannis, Validi, Dani, Antoniou, 2019]. This is the opposite of the next more level, where these probabilities are unknown and SCRM can only rely on subjective beliefs. While the supply chain risk management process has been extensively researched, that has not been the case for CNC machine service and research into risks associated with machine down time. A process of Risk Assessment for CNC machine service certainly benefits from an objective rather than a subjective process, as long as the focus is based upon quantitative data items in a deterministic model. This introduces an original contribution to the body of knowledge to the service operation and process.

From the view of risk management for the purpose of controlling or completely avoiding the negative effects of risk means negative effects will be minimized and/or eliminated. The result would be improving productivity and profitability of the CNC machining operation. This research has been addressed in the areas of Supply Chain Risk Management as well, “After all, SCRM is only effective if the structure of the supply chain is at least fully understood”. [Baryannis, et al., 2019].

2.2 Classification Models

2.2.1 Problem Evaluation

Computer Numerical Control (CNC) machining is an integrated process with several different manufacturing business categories. These manufactures are quite diverse and spread over numerous products and markets, which could be consumer products, aerospace components, medical equipment parts, etc. These manufacturers work to coordinate, convert, and process raw materials into a final product [Beamon, 1998].

The customer participates in the CNC downtime risk and an alternative from a customer perspective is that machine down time will cause delays in parts made by the CNC machines, whereas the objective is to fulfil a customer request. [Franca, Jones, Richards, Carlson, 2010]. Since the late 1990s there has been an increasing focus on the performance, design, and analysis of CNC machine down time, and the manufacture of machined parts is an integral part of this supply chain [Beamon, 1998].

The purpose of a CNC machine down time analysis is to maximize profit in a process of generating value for the customer [Franca, Jones, Richards, Carlson, 2010]. In other words, the analysis purpose is to maximize the difference between the final product worth and the cost incurred by the CNC machine down time in order to deliver the product to the customer on time and within cost constraints. The information gained by the analysis can be used in the work process of managing CNC machine down time, where the aim is to increase competitiveness [Snyder, Atan, Peng, Rong, Schmitt, Sinsoysal, 2016]. Furthermore, this research maintains that continuous work on management of CNC machine down time will help visualize how the CNC machine productivity and affects part production and distribution but is not always an isolated aspect of the supply chain. This research also maintains, that in order to deal with productivity problems, having knowledge of costs and stock levels are not adequate enough to address downtime productivity issues, since no quantitative model can capture all aspects.

Economic systems are experiencing increasing uncertainty and complexity [Heckmann, Comes, Nickel, 2015]. A shift in risk management has occurred and companies now render more informed decisions with the aid of risk: assessment, control, and mitigation tools. This position is also presented by authors [Gaudenzi, Borghesi, 2006], who contend that weaknesses within the supply chain are the results of increases throughout competitive global environment. [Svensson, 2002] contends that dependencies between organizations will create vulnerable situations and companies will need to address these with the assistance of risk management and risk assessment. When addressing risk assessment there are two views to consider according to [Gaudenzi, Borghesi, 2006], which are:

- Risks occur at various intervals, inside the company as well as at a network level.
- The estimation of risk is vastly subjective, due to analyst's individual concept of what signifies a risk.

The use of lean techniques and timely Just-in-time concepts in production and logistics can improve efficiency. However, since the supply chain leaves little room for errors and changes, the supply chain is susceptible to adverse events [Aqlan, Lam, 2016]. Additionally, companies are becoming more global, and their degree of vertical integration is decreasing, which is thereby increasing the complexity of the supply chain and exposing it to more risk [Behzadi, Golnar, 2018]. This very issue now exists within the CNC machining manufacturing environment as well. Finally, countless incidents that disrupted the global supply chain and have been seen in recent times, which have attracted worldwide attention. For example, such things as natural disasters (the tsunami and floods in Japan that caused a global shortage of many products from that region to man-made disasters (like the 9/11 terrorist attack). This also includes the current 2020 global economic crisis caused by the COVID19 pandemic, leading to health, financial and economic instability, not to mention the political consequences

While Supply Chain Risk Management (SCRM) this is a well-known practice within the logistics community, which encompasses research of many different methods, from qualitative methods (such as empirical research and conceptual theory) to quantitative methods (such as linear programming optimization, data analysis, and mathematical modeling). Regarding implemented strategies, SCRM can employ passive or active strategies: the former is applied after risks have arisen, while the latter allows identification and assessment before risks arise in order to develop appropriate mitigation and contingency plans, [Baryannis, Validi, Dani, Antoniou, 2019]. Aspects of this research are the very topics that now add to the body of knowledge within the areas of CNC machining which this research has identified as not currently being employed and this research is developing the application of these concepts.

Recent events such as the KFC chicken supply crisis in early 2018 have further demonstrated the view that weighing risks and developing contingency plans before major changes in the supply chain can potentially prevent major losses [Green, 2018]. To achieve this goal, proactive strategies rely on the ability to accurately predict the likelihood of occurrence and the impact of potential risks. A wide range of technologies can be used to achieve this necessary predictive capacity. [Baryannis, et al., 2019].

Financial risk assessment is another common area of the application of risk assessment. Forecasting methods play an important role in the development of early warning systems for financial crises. The use of several different algorithms (e.g., NN, Decision Tree and SVM) to predict the financial distress of a group of companies based on 31 financial indicators [Geng, Bose, Chen, 2015]. Recently, predictive models for intentional and unintentional financial adjustments have also been developed [Dutta, Dutta, Raahemi, 2017]. They use a variety of classification algorithms (such as ANN, decision trees, naive Bayes, support vector machines, and Bayesian belief networks) [Dutta, et al., 2017]. Other methods also used in research have been decision trees, support vector machines (SVM), neural networks (NN), and logistic regression to collect data from 100 US companies that went bankrupt and compared the performance of these algorithms [Tobback, Bellotti, Moeyersoms, Stankova, Martens, 2017]. Likewise, used methods for classifying the neighbors with weighted voting relationships to predict the insolvency probability of SMEs based on financial and non-financial data.

Risk usually originates from a lack of information, and its identification is an intricate and costly process due to the high uncertainty of event occurrence and difficulty in collecting and analyzing the risk data [Karaa, Fırata, Ghadgeb, 2020].

2.2.2 Problem Background

These are the circumstances surrounding necessary service; corrective, preventative, and predictive, and how to structure the service maintenance process. The choices are to divide the function into three categories: i- in house (SM-1) service, ii- service contract (SM-2), and iii- third party service providers (SM-3).

i- capabilities of the SM-1 are quick response on routine repair and maintenance, while maintaining minimal repair part inventory

ii- capabilities of the SM-2 are reasonable response time and additional capabilities for specialty and larger scale repairs and maintain a larger replacement parts inventory and part supply network (and/or warehouse).

iii- capabilities of the SM-3 are more final recourse when the service is beyond the scope of SM-1 & SM-2. This is critical when it requires specialties which only a third part service supplier is capable of and the impact of the risks associated with the service event will potentially have a serious impact on the organization and productivity. This has a strong impact upon the inventory and warehousing maintenance function by requiring less storage of spare part quantities.

An important technical challenge is to identify the potential risks posed by new product launches and the strategies to mitigate those risks. Sources of these potential risk factors can be from within the organization internal; technical abilities, human resources, suppliers, and stake holders, or external; supply chain partners, such as third-party suppliers, customers, and service providers as well as competitors, and political, social, or environmental forces.

This implies that an effective risk analysis should not only focus on the total lifecycle stages of a product but extends to multi-lifecycle material flow, [Enyoghasi, Brown, Aydin, Badurdeen, 2019]. Qualitative and quantitative capabilities for modeling and evaluating product design risks have been addressed in literature, [Enyoghasi, et al., 2019]. However, the models developed in the literature have nothing to do with determining the functions available for optimal product configuration design, making them less reliable in decision making. Effective decisions for sustainable product design must incorporate risks and uncertainties into the optimization of the product configuration design, [Enyoghasia, Badurdeena, F., 2020]

2.3 Research Methodology

2.3.1 Purpose

The purpose of this research is to develop a quantitative method of assessing risk within the CNC machining operation by integrating multiple activities. Examples consist of identifying risk indicators, collecting, and storing risk data, converting risk management problems into the Analytical Hierarchy Process (AHP), and identify information using the AHP to analyze and interpret the results. Risk mitigation strategies. To implement this framework, knowledge of interdisciplinary areas and several methods of data collection and evaluation are required. Literature on Supply Chain Risk Management, relating to logistics and information management systems were reviewed to assess comparative models. Key steps in the overall AHP process are identifying the risk management team and choosing the hierarchal components, which are critical roles in developing this complex model. The conceptual model was developed refined and verified using simulation data in excel. The type, severity and frequency of the risks vary depending on several factors associated with the CNC machining process. CNC Machining operations vary, and each has its own risk profile and risk components. Therefore, the tests propose varying frameworks in order to gain important insights, of the operation.

2.3.2 Operational "Body of Knowledge"

An addition to the CNC operational body of knowledge making this research unique to the integration of this research into both the CNC machine controller as well as the with ERP (Enterprise Resource Planning) software in order to integrate service within the processes already incorporated within ERP (personnel, procurement, production, R&D, sales, transport, finance, etc.). Through this process now CNC service/maintenance can be integrated into one platform and thus improve process management to gain competitive advantage. Hence, the AHP method was chosen to quantify service risk in this case.

A point that the evaluation of risk is subjective also indicates that there are also several different definitions of what CNC machine down time risk could be. Investigating comparisons of risk definitions has helped come up with a definition that should cover the entire manufacturing machining process [Ho, Zheng, Yildiz, Talluri, 2015]. The definition of risk from this review which can be applied to CNC machine down time is as follows, "the likelihood and impact of unexpected macro and/or micro level events (interruptions/failures) or conditions that adversely affect any part of a CNC machine (down time) leading to operational, tactical, or strategic level failures or inconsistencies within the product/process flow "[Ho et al., 2015, s. 4]. It must also be clear that there is a difference between uncertainty and risk. Risk is the perceived possibility of events and can be represented by measured probabilities in a given situation. Uncertainty is when the possibility of events cannot be measured due to the impreciseness of a given set of circumstances [Epstein, 2004].

2.3.3 Down Time Risk

CNC machine down time risks and risk factors may be identified in several ways. This may all be in the eyes of the observer [Gaudenzi, Borghesi, A., 2006]. What this implies is that risk should be connected to the objective of CNC machine down time reduction to facilitate selection and grading of different risks.

Risk assessment is an untapped research resource of improved productivity and profitability that should be highly connected to the objectives of manufacturing machine operations. This is the very aspect of this research that makes it so unique in the CNC machining environment. The amount to which these objectives are accomplished is dependent upon the magnitude by which the uncertainty within manufacturing exists [Heckmann, Comes, Nickel, 2015].

Some studies have tried to incorporate “soft values” to risk assessment into optimization problems in an attempt to further develop a realistic solution to a wide range of different problems which may apply to CNC machine down time risks.

2.3.4 Optimization

An optimization model for the time sensitive products has been created, which may also be applicable to CNC machine down time. The model aims to solve an allocation problem by minimizing risk and cost throughout the manufacturing process [Nagurney, Masoumi, Yu, 2012]. This model could be reconfigured to be applied to different problems. In case, a general network optimization model with integrated risk assessment would need to be developed for the risks associated with CNC machining.

In this study it is intended to assess multiple service risks which can interrupt product process flow from manufacturing to finished goods (customer), considering cost and risk. This will help develop the AHP model that helps manufacturing personnel choose the best process flow for machining operations based upon risk factors. This will be accomplished by investigating the following topics:

- What risks exist within the different process flows?
- What are cost variations through different process flows?

• How is risk assessed and compared to costs as different process flows are evaluated?

2.4 Model

2.4.1 Adaptation of Risk Model

This model is a unique adaptation of risk assessment tools applied to CNC machine down time which has never been applied to the fabrication cycle before. It is not designed to help solve or minimize identified risks. The objective of the model is to reveal the risks and costs to the organization and assist with making well informed decisions so unnecessary risks and costs can be minimized.

The model results in an analysis utilizing spread- sheets simulation for the risk model which outlines the likelihood (in terms of number of possible events in a given time frame; for example, 1 in 5 years,) and duration (estimated using a triangular distribution due to its intuitive nature) of each disruption category A process flow diagram has been developed to display the phases of service maintenance. This diagram illustrates the levels of service provided while identifying the relationships between the different levels and the inputs and output controls and resources associated with the service process.

Figures: 2.1 and 2.2 show an overview of the hypothetical distribution channel setup.

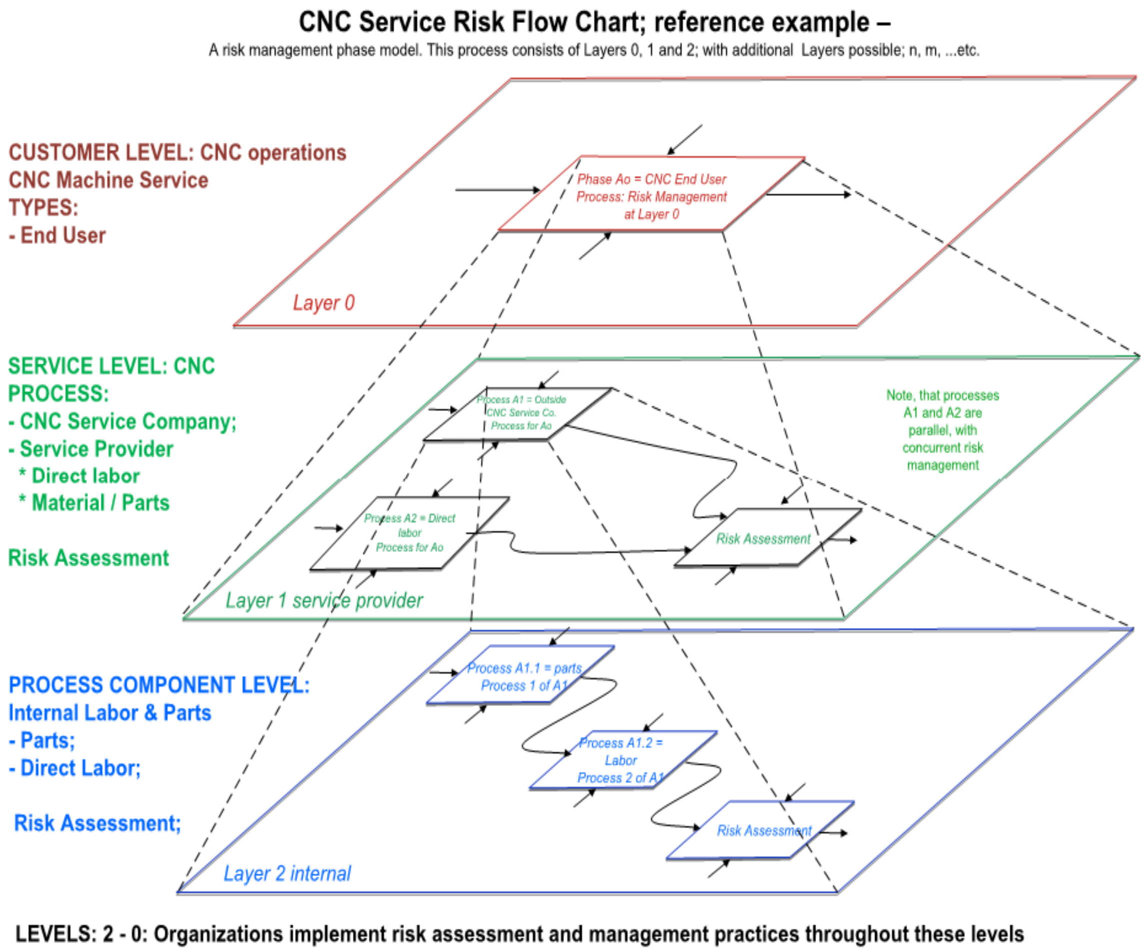
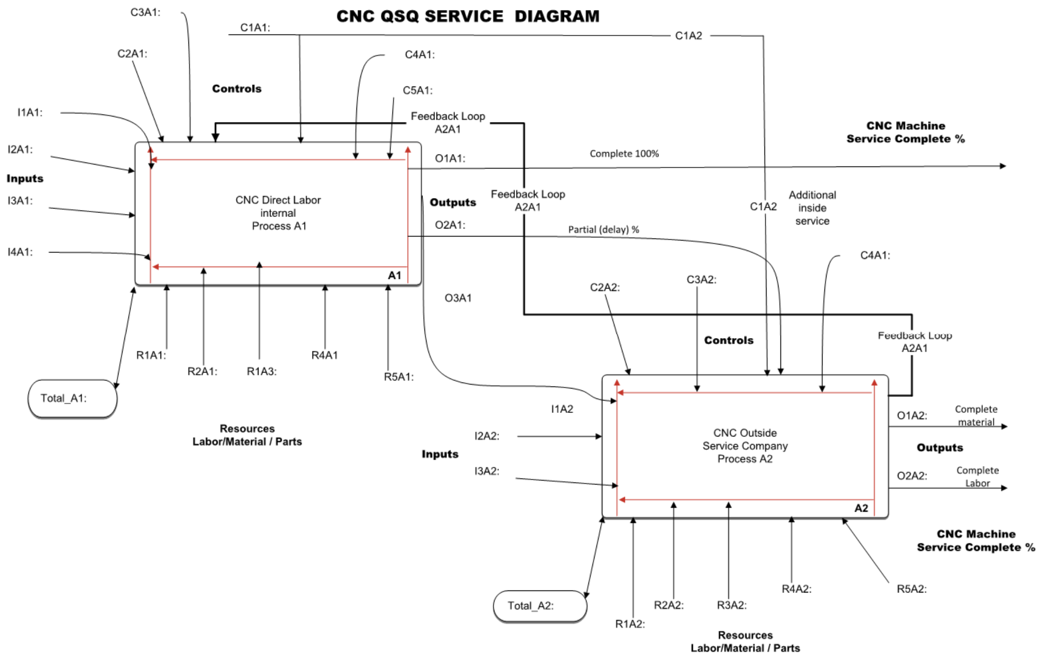


Figure 2.1 System risk process model.



Level 1 & Level 2 QSQ service system diagram Ref.: **Sample Service,** Date: **Xxx 00, 2020,** Version: **Ver. 1.0**

Figure 2.2 System service diagram.

The model does not solve the risk related problems, merely the identification of the potential existence of the risks and the analysis of relative differences in risks between production process flows. The study does not include model integration or any practical data, but the development of simulation ad-hoc data is implemented. To increase validity, we use a pilot random generator of data parameters within the model. Consequently, the reliability of the model results is harder to assess for this method. The evaluation of risk perceived within model for CNC machine down time is highly subjective, which could lead to not taking a critical enough approach to areas of improvement and reliability within the production environment.

2.4.2 Researched Alternative Risk Models

2.4.2.1 Data Mining (DM). In order to develop a data-driven framework to CNC down time risk, the key principles of data mining (DM), data warehouse and risk management are systematically integrated. Figure 2.1 shows a step-by-step method for developing a DM-based framework. The core phases of the proposed model are: (i) identification of risk indicators, (ii) development of a risk data warehouse to collect and store risk data, and (iii) inclusion of a DM module that converts risk management problems into DM problems and explains risk management analysis results measured, [Karaa, Fırata, Ghadgeb, 2020].

2.4.2.2 Multi-Criteria Decision Making (MCDM). This is a popular concept that aims to find the most qualified alternative from a range of alternatives based on a range of criteria. These are techniques that can be used for various decision-making processes within management, business, society, and other fields. MCDM has two technologies.

There has been a realization that most models in the past were based on deterministic factors. In reality, however, it is difficult to know the exact production capacity and demand impact risk will have upon the operation. For these reasons, the uncertainty of the risk factors must also be taken into account.

While the risk factors of production and procurement problems are usually reviewed and managed as separate problems, there are many similarities in the fundamental issues. In addition, the uncertainty of the parameters of production and procurement are not addressed as thoroughly as other aspects of an organization as they tend to be more pragmatic and inconsistent, [Kaura, Singh, Garza-Reyesc, Mishrad, 2020].

2.4.2.3 Mixed Integer Non-Linear. Another model developed for this purpose is Mixed Integer Non-Linear Program (MINLP). This model takes into consideration all the production and procurement constraints to procure dependent items to meet independent items from the selected suppliers and their carrier to maximize revenue as well as to minimize procurement and costs. [Kaura, et al., 2020].

2.4.2.4 Mixed Integer Linear. An additional mathematical model for optimization is Mixed Integer Linear Programming (MILP) for optimization Industries [Zhang, Shah, Wassick, Helling, van Egerschot, 2014]. Heuristic methods are also used to model problems in SSCM. [Vivas, Sant'Anna, Oliveira, Freires, 2020]. The results show a data-driven model that predicts the optimal decisions with important accuracy, time efficiency, and flexibility to simultaneously handle several uncertainty sources disregarding their distributions, [Cedillo-Camposa, González-Ramírez, Mejía-Arguetac, González-Feliu, 2020].

2.4.2.5 Heuristic. Final methods to be considered are a heuristic in nature and use qualitative information to develop a quantified solution. The basic premise is that human technology is based on human preferences, such as: Analytical

Hierarchy Process (AHP) and Best Worst Method (BWM), [Abdel-Basset, Mohamed, 2020]. The BWM method has a significant limitation as this method restrictions the analysis to only two choices. This may skew the results depending on the gap between the two points of information. For this reason, this technique is not a preferred method for this research.

2.4.2.6 Analytical Hierarchy Process (AHP)

The chosen method in this research is AHP, because of the ease of development within a production environment and the use of operational knowledge to develop a solution based upon the wide variety of relevant information necessary to address the risk within CNC machine service.

Some studies of 4.0 industry have provided illustrations that offer economic examples which allow for the evaluation of productivity and technical efficiency of regional manufacturing industries, [Cedillo-Camposa, et al., 2020]. Results shown in research demonstrate that for both the standard model and the proposed factorial model, the economic theory is validated in terms of the importance of the inputs that form the manufacturing outputs, [Cedillo-Camposa, et al., 2020].

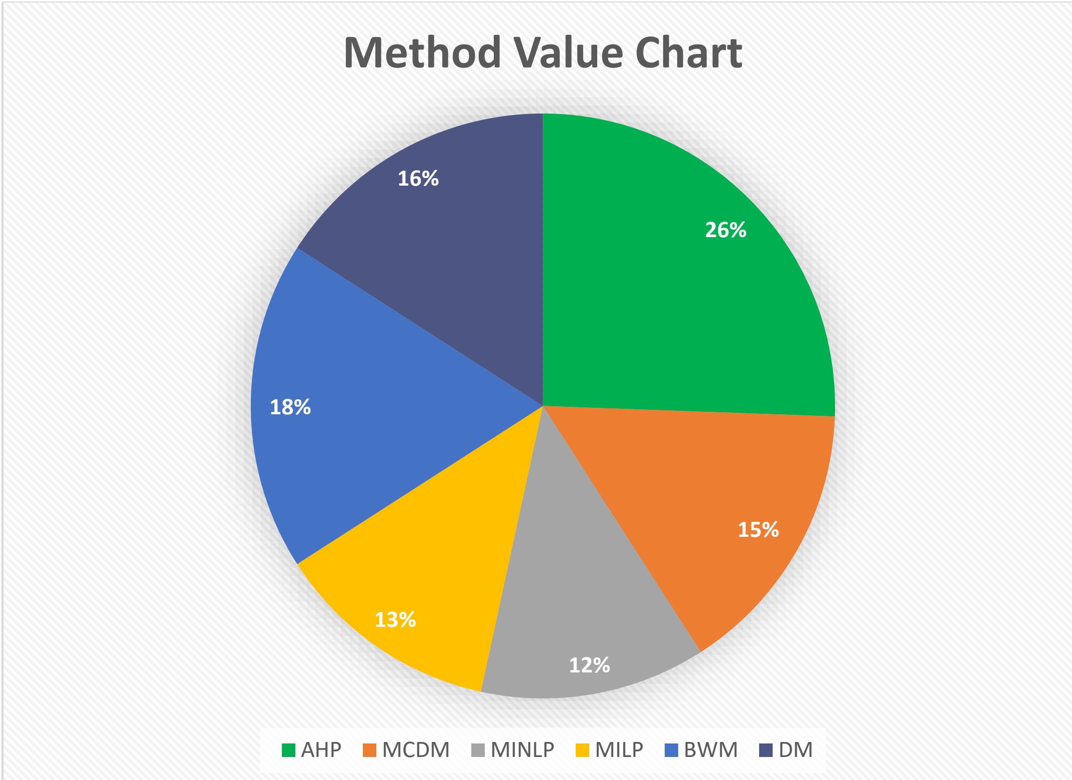


Figure 2.3 Method comparison value chart.

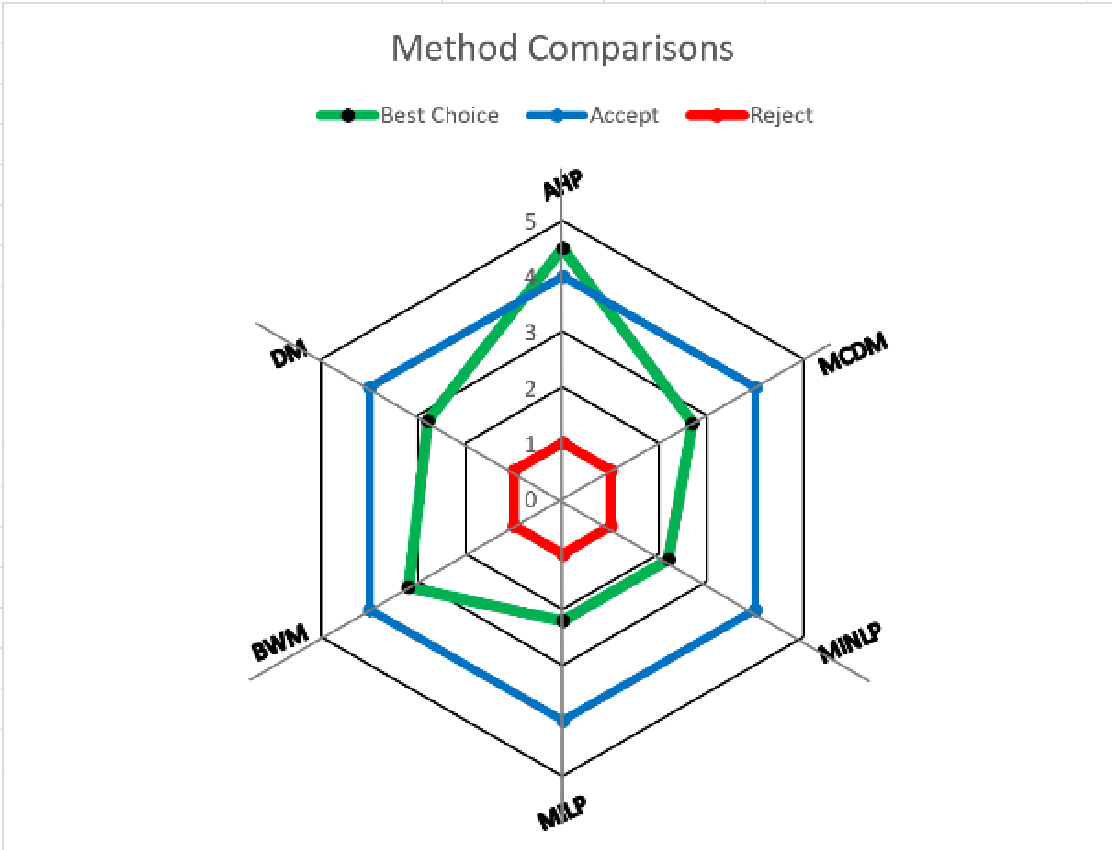


Figure 2.4 Method comparison radar chart.

2.5 Quantitative Method Analysis

In this section the method of analyzing quantitative information is presented in the research. In particular, the analytical hierarchy process (AHP) is discussed and developed.

2.5.1. Analytical Hierarchy Process

The analytical hierarchy process (AHP) enables an organization to assemble and configure the identified risk components impacting the decisions process in a ranked format from top down in an analytical process of criteria, sub-criteria, and alternatives [Saaty, 1990]. The creation of the hierarchy starts with the measurement step of the criteria and then moves down to the sub-criteria level. An application of AHP to the CNC machining processes is an approach that minimizes machine down time and fabrication interruptions.

A link should be established between risk and cost of the steps in the process. Cost may be integrated into the risk AHP to address this subject. Addressing this item of risk and cost relationship results in identifying risky criteria during CNC machine service. Once this is done the more specific risk sub-criteria aspects of this analysis are fully identified and integrated into the model to understand how these sub-criteria can affect results of process. Costs are inherently connected to alternatives therefore cost is not broken down into further sub-criteria.

Different aspects of identified risk must be assessed as well to determine the potential impact on the service process flow when making the decision of what service alternative should be implemented. This is not necessary for the cost aspect as these are associated with the risk component, and not directly associated with the product cost, or the quantitative quality of the service.

After the construction of the AHP hierarchy, the element priorities need to be determined. This is done by establishing the parameter range of the different elements for a given criteria and assigning a value for the criteria for each element.

Heuristic values between $0 \leq x \leq 5$ are chosen for the following comparisons.

1. Between criteria with respect to goal,

2. Between sub-criteria with respect to goal

3. Between alternatives with respect to sub-criteria

4. Between alternatives and elements

The comparison of the alternatives with regard to cost criteria is not done, as this is a process which can be done numerically when the costs of the different flows are calculated.

Every value between the n criteria will create an "x" and a corresponding inverted value 1/x to create a n * n matrix in example below figure 2.5,

$$\begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{..} & x_{1n} \\ x_{21} & x_{22} & x_{23} & x_{..} & x_{2n} \\ x_{..} & x_{..} & x_{..} & x_{..} & x_{..} \\ x_{n1} & x_{n2} & x_{n3} & x_{..} & x_{nn} \end{bmatrix}$$

Figure 2.5 Criteria matrix.

Next, we create the priority vectors. This is the Eigen vector of the matrix figure 2.6. This can be manually calculated but is shown here using a computer solution (MS Excel). Using the example matrix in Figure 2.6, each row represents one of the four criteria:

	A	B	C	D
Criterior 1	1.00	3.00	5.00	2.00
Criterior 2	2.00	1.00	1.00	3.00
Criterior 3	3.00	1.00	4.00	2.00
Criterior 4	1.00	2.00	4.00	1.00
	7.0	**7.0**	**14.0**	**8.0**

Figure 2.6 Criteria values.

The first step is to normalize the matrix; this is accomplished by dividing each column component with the columns sum. This will make the new sum of each column equal to 1. This results in the Matrix in figures 2.7 and 2.8:

$$\begin{bmatrix} 0.14 & 0.43 & 0.36 & 0.25 \\ 0.29 & 0.14 & 0.07 & 0.38 \\ 0.43 & 0.14 & 0.29 & 0.25 \\ 0.14 & 0.29 & 0.29 & 0.13 \end{bmatrix}$$

Figure 2.7 Eigen vectors.

	Normalized				Priority
	A	B	C	D	
Criterior 1	0.14	0.43	0.36	0.25	29%
Criterior 2	0.29	0.14	0.07	0.38	22%
Criterior 3	0.43	0.14	0.29	0.25	28%
Criterior 4	0.14	0.29	0.29	0.13	21%
	1.0	1.0	1.0	1.0	100%

Figure 2.8 Excel version of eigen vectors.

To calculate the priority vector, we use the average of each row, since we normalized the matrix the sum of elements in the vector will be equal to 1. This process of normalizing the matrix is accomplished through the formulation of this procedure within the excel spread sheet developed for this purpose.

We get the following priority vector:

$$\begin{bmatrix} 0.29 \\ 0.22 \\ 0.28 \\ 0.21 \end{bmatrix}$$

Figure 2.9 The priority vector.

In this example the criteria 1 has a relative weight of 29%, the criteria 2 a relative weight of 22%, criteria 3 a relative weight of 28% and the last criteria 4 a relative weight of 21%. As demonstrated here this is a superior method of prioritizing risk values associated with the CNC service maintenance process because it quantifies the utilization of current traditional subjective and qualitative methods in use today in CNC service maintenance risks. This unique method is used to apply an acceptable mathematical quantitative analysis tool to the risk assessment and management of CNC service operations.

When analyzing the result, you should look at the consistency of the comparisons. In this study we evaluated the consistency index from the simulated values and compare it to the Random Consistency Index displayed in table.

The consistency index (CI) is calculated by the AHP criteria by dividing the minimum number of criteria (in this case 1) by the actual total number of criteria (4x4) used in this analysis. Therefore, CI = 0.0625

Table 2.1 Random Consistency Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

n= occurrence, RI= random index

Based on the number of criteria that we use; the random consistency index increases in value. When we have all of the elements, we use the consistency index (CI) given by the AHP excel program used and compare it to the random consistency index (RI) in order to calculate the consistency ratio (CR). This is done accordingly:

CR = CI / RI CR = 0.0625 / 0.90 = 6.9%, therefore this assessment is consistent. If CR is below 10% the subjective evaluation is considered consistent [Saaty, 1990].

2.6 AHP Method Discussion

It is generally understood that during the process of CNC service maintenance some form of risk analysis is a valuable, and necessary component of the process. Quantitative Risk Management is the process of applying quantifiable Quantitative Risk Analysis (QRA) results determined during a risk assessment into useful information for the management of risk within the organization [Moriarty, 2021a]. This is commonly accomplished by assigning impact scores, rankings, and probabilities to the subjective and qualitative inputs from the most knowledgeable stake holders. Then a variety of mathematical processes are applied in order to acquire a value for risk severity [Ahmed, Hani, 2017]. This process of quantitative analysis can then be applied to both costs and schedules.

Typically, in project management, schedules are managed by systems such as Critical Path Method, (CPM) networks, Project Evaluation and Review Techniques (PERT) analysis, or Monte Carlo Simulation. Quantitative analysis of cost is usually a culmination of the individual tasks or “work breakdown structures” (WBS) of the project. Then an analysis of the estimated time and impact of delays can be conducted using simulation methods e.g., Monte Carlo analysis, or analogous analytical techniques. Some observed practical studies have been done in this area of risk assessment and response planning. One organization that has devoted a great deal of effort to the subject is “The Project Management Institute” (PMI). Risk planning based upon established risk response planning, encompasses the determination of best practices and most effective mitigation methods (Project Management Institute, 2000).

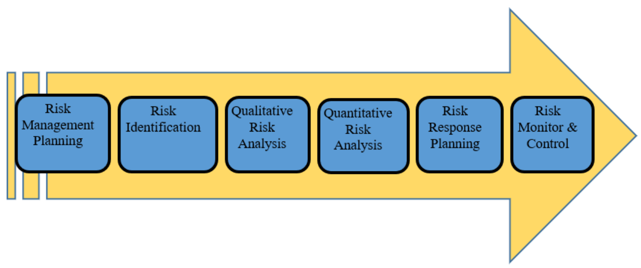


Figure 2.10 Risk Management Process Flow [PMBOK, 2014].

The process of Response Planning can usually be performed after the qualitative stage or may also be accomplished after the quantitative stage. Either stage is acceptable due to the fact that maintenance goals will vary based on current circumstances and may be dependent upon the impact on the risk planning.

The key objective during the risk-response planning phase is avoiding a risk, for example availability of necessary replacement parts is key and that varying availability from time to time can be an issue. Availability of key resources or capacity may also assist and can ensure the reduction of a risk.

This can be accomplished heuristically, performed in a hierarchical style as presented earlier under the Quantitative Methods section utilizing AHP. This process is developed in a group setting of key contributors. In the CNC production area, the risks having the greatest impact on down time and production interruptions should be addresses first. One of the most effective methods of analyzing risk is through the use of historical machine and maintenance data using machine monitor and control systems [Moriarty, 2021a].

The last step in this process evaluating and managing risk is risk monitoring and control. This requires, persistent checks, reexamination, scrutiny, and surveillance to ensure no variable changes have occurred or have been introduced into the process. Changes within the organization internal or external may impact the circumstances of how the steps in the plan are affected. To accomplish this, function an individual or team should be assigned the task of checking the process by inspection, survey or questionnaires of key people, and responsible roles within the organization, e.g., plant managers, department manages and CNC operators. This must be a continual process requiring comprehensive record keeping and regular reporting [Moriarty, 2021a].

2.7 Chapter Summary

This chapter presents the research done on investigating risks associated with providing a quantitative method of service quality on CNC Machine Tools risk factors. The results of this research have created a method of quantifying risks associated with CNC machine service. Additionally, a generic tool has been created which is utilized for evaluating and assessing these risks. This tool provides the means of creating a quantitative measure of risk assessment to better identify and prioritize risks which enables the organization to better manage CNC machine down time. It is of great importance to modern organizations that use sophisticated highly engineered systems i.e., CNC Machining Centers to manage risks resulting in production interruptions. The results of this risk management process improve productivity and reduces CNC down time, and therefore increases output and product yields. This process also considerably improves the overall performance of the organization. CNC machine maintenance and downtime are major causes of poor quality, inefficient performance, and low productivity throughout high-tech operations. While the focus of this research is specifically on CNC machining these same methods and techniques can most certainly be applied and utilized within all highly engineered systems. A substantial number of operational interruptions are due to machine down time as a result of either scheduled or unscheduled maintenance. There is currently no systematic means of CNC service data transmission and collection as well as a lack of quantitative service quality data systems capable of delivering this information. While numerous manufacturing management systems throughout production operations have been implemented over time, none of these systems address the risks associated with poor service quality and process interruption or the minimization of operational downtime. This constitutes a management approach unrecognized in the past and will usher in a fourth generation of in the world of maintenance.

While it is true that modern maintenance programs have effectively improved the efficiency of operations, efforts to introduce changes to service quality have gone unchanged for a long time. Most service systems have not been as successful in improving the operational productivity because of the complexity of machine maintenance and a lack of full understanding of the unique aspects of highly engineered technical equipment i.e., CNC machines.

The integration of an automated service data system utilizing unique quantitative methods to identify, assess and prioritize machine maintenance risks has disclosed a significant opportunity to enhance the risk assessment and management of service-related interruptions within the organization.

This research identified, examined, and develop a modern systematic method of addressing risk assessment and management.

The AHP analysis and priority matrix methods are identified as key aspect of this process and an excel simulation approach has been used to model potential occurrences of variable risks when estimating the prospective effects identified risk factors may have on the production process.

The simulation successfully ascertained the priority values for the risk criteria identified in the model and the impact on the process. This has now given the CNC service environment a tool to assist in the improvement of product quality, productivity and reducing the impacts of production downtime and interruptions.

In summary, even though there has been a great deal of study conducted on the topic of risk throughout may industries and areas of interest to the best of my knowledge there has been no quantitative research into risk management of CNC maintenance service quality and the prioritization of criteria in the dynamic realm of CNC machining operations.

In an effort to minimize and minimize the impacts of unknown and known risk factors which could interfere with the productivity and profitability of CNC operations by interrupting the manufacturing process, it is crucial to develop tools to predict the effects of key risk factors beforehand in order to avoid, eliminate, or minimized the consequences of such risks. The weaknesses inherent to this research are the limitations of a simulation model in comparison to actual operations [Moriarty, 2021a]. The volume of possible variations has been limited in this research.

While the possibilities, probabilities and the impacts of risks factors may continually change over time, varying risks will have a much more profound effect on CNC operations if identified too late. This will, in turn make it difficult to manage the consequences of risk, may cause more damage and be much more expensive.

Consequently, the intention of this research is to prepare CNC service operations in recognizing risk factors as a foundation of the risk assessment & management process and perform the analysis in the initial stages of the Risk Management process to identify and quantify risk priorities.

CHAPTER 3

LIFE CYCLE ANALYSIS

The central focus of this concept is directly concentrated on 'computer numerical control' (CNC) machine tool systems. These concepts specifically address this category of engineered systems. A Quality service systems concept is a unique approach to maintenance service. Standard product service systems are qualitative and subjective in nature. This quantitative system identifies Key Predictive Attributes (KPAs) that identify unique concept application techniques and applies quantitative methods to attributes which develop a systematic process of analyzing and monitoring the system. This research is reviewing the specific projection of service outcomes for Machine tool CNC machining centers. The specific key predictive attributes are the elements being utilized in the created modular function in this research, to assess the potential impact of discrete elements of these attributes as it affects the occurrence of equipment down time for a system which will work to quantify the service quality of the maintenance process. This project is unique in that currently there is no system which utilizes methods or tools, that proactively gather, analyze, assess, and project outcomes of equipment "Down Time" of the Service Quality process. The innovative position of this analysis is one of actual variable tolerances, versus a more traditional nominal referenced variable reference. What makes this research unique additionally is the system is pre-service and not post-service reporting of actual down time of the equipment. This research is much more than pro-forma estimate of service outcomes [Moriarty, 2021b]. Another unique aspect of this method is that it has established tolerances values to assess the performance of the Service Quality process does not just rely on nominal values. Mathematical Upper Control Limits (UCL) and Lower Control Limits (LCL) are programmatically developed based upon the system data. Additionally, the system has developed programming algorithms which drives the current process from a subjective, qualitative process to a more robust quantitative projection tool. The advances of this research is the development of the quality index through the creation of the Moriarty/Ranky Transform approach.

3.1 Basic Understanding of CNC Component Life Cycle

The purpose of this research is to present the set of quantifiable measures for the prediction and performance of quality maintenance of CNC manufacturing equipment for improving productivity and reduce machine down time due to unscheduled and scheduled maintenance functions that can be applied to this equipment. In this section of the research, the analysis is a unique methodology presented as applied to the quantifiable analysis in terms of major “Key Predictive Attributes” (KPA) aspects. A comprehensive component life cycle analysis, cost factor reviews over the equipment’s four steps of product life cycle: Material & Supplier, Manufacture Production/Assembly, Use/Operation (which is not component of this research study), Quantified Service Quality Maintenance and End of Life (EoL) steps. Material types include: (e.g., steel, aluminum, titanium, and composites, etc.), manufacture process (casting, forging, removal (machining) and/or additive (3D printing) manufacturing and assembly methods (manual, semi & automated and/or robotic). A quantifiable scoring method Moriarty / Ranky Transform (M/R T algorithm) has been developed and used to decide how certain attribute factors affect the prediction of maintenance outcomes using these scenarios [Moriarty, 2021b]. The factor categorized into two groups: operational, and technical groups. Each group has analogous features which are (or may be) utilized, so only important KPAs have been selected in the application of this research. The actual dissertation proceeds to develop and validate scoring methods to get a better understanding of the relative M/R T ranking for different maintenance applications circumstances. This work has examined the application and role of multi-criteria activities and methods in assessing and predicting the outcome of projected maintenance functions and activities.

Materials selection methods include quality function deployment (QFD) and analytical hierarchy process (AHP) [Chen, Yang, Lin, Yeh, Lin, 2007], [Saaty, 1990]. The addition of multi-criteria variable selection methods are tools which assist in the choice of alternatives, particularly when conflicting goals exist [Sapuan, 2001], Sapuan SM, Jacob MSD, Mustapha F, Ismail N., 2002]. And then the use and or creation of a knowledge-based system (KBS) to establish the computer resource technology and means of managing the quality service modeling process [Sapuan, Abdalla, 1998], [Shehab, Abdalla, 2002]. The goal behind using KBS is to help designers, service managers, technicians and machine operators establishing the KPA data and generation of the Predictive

Quality Service System (PQSS) index value for associated with necessary equipment service.

There are numerous researchers today exploring new methods in CNC machine control to monitor and improve quality of machined parts. Many prediction models based on empirical methods are used to analyze the relationships between machining parameters and part quality. Practical data has been identified for further development of optimizing machine control, and many have been built upon Artificial Intelligence (AI) algorithms [Mia, Morshed, Kharshiduzzaman, Razi, Mostafa, Rahman, Kamal, 2018]; An example of this empirical approach using AI as a prediction model for material condition was developed [Mia, et al., 2018], which intended to optimize machining conditions by minimizing the machine forces thereby improving part condition quality.

While there has been a great deal of research done on many aspects of CNC machine control and productivity interruptions, none have addressed the down time in product return issues, they have not addressed a quantitative, prognostic, predictive method to improve the service provider's performance. Previous research verifies Adaptive Control (AC) has been introduced as an effective method of optimizing machining parameters in the past [Kucukkoc, Buyukozkan, Satoglu, Zhang, 2015], [Lim, Zheng, Chen, 2019]. More recently, the implementation of fuzzy logic models for predicting and controlling part condition has been investigated and implemented as a method of improving the machined part quality of key components of the machine. Continued productivity of CNC machines can be monitored through the ability to model process down time risk.

The incorporation of fuzzy logic controllers to assist in controlling and predicting part quality has increased in popularity [Volpe, Fontes, Embiruçu, Kalid, 2018].

Within the new age of Smart Manufacturing and Industry 4.0, product life cycle management (PLM) and prognostic health management (PHM), a key connection must exist between these and data management systems, [Xia, Dong, Xiao, Du, Pan, Xi, 2018]. Within several applications of 3D printing (additive manufacturing) there has been extensive development and support for PLM and PHM [Kaewunruen, Lian, 2018].

This research addresses the next generation of service maintenance, which is a unique approach developed as Quantifiable Service Quality. The focus is on the preliminary materials suppliers, manufacturing /production/assembly method, Quantifiable Service Quality maintenance, and EoL analysis. The combination of the material selection principles with decision making methods are a means of developing multi-attribute material selection methods instead of utilizing only one objective at a time [Jee, Kang, 2000], [Mia, et al., 2018]. Consider a machine contains ″n″ number of parts, each component has ″m″ material options, each material there are ″s″ supplier, ″p″ production methods, ″a″ assembly processes, and finally for each of these material options ″e″ EoL possibilities exist, Therefore, m^n x s^n x p^n x a^n x e^n solutions are possible. As a result, the objective of the life cycle analysis cost estimation is to minimize the service cost and the production impact (its productivity impact) throughout the equipment product life cycle.

The overall objectives are to minimize the service costs and productivity interruptions through quantifiable service quality system methods and equipment life cycle management. This model is designed to assess different issues simultaneously, namely: material alternative selection, supplier selection, manufacturing and assembling process selection as well as the actual service functions and equipment EoL options. This unique M/R T algorithm can be used for solving multiple causes simultaneously e.g., component alternatives, supplier selection, production and assembly processes and service options and the EoL option determination of the equipment [Moriarty, 2021b].

3.2 Classification Models

The use of classification models of optimal part/service configuration selection assessment is difficult and quite time-consuming. It is impossible to solve this multitude of configurations in consideration of the magnitude of design alternatives to achieve an optimal configuration. In this document an original quantitative services quality evaluation method creates a service index value, which takes quality functional development to the next level derived from the multi objective optimization model developed to assist with the selection of the optimal combination of supplier, material, production, and assembly methods in the shortest possible time.

a) Multi-criteria decision-making approaches and

b) Multi-objective decision making and

c) Life-cycle analysis methods

Life cycle analysis (LCA) methods have developed comprehensive frameworks configurations to select sustainable life cycle assessment perspectives [Mayyas, Shen, Mayyas, Abdelhamid, Shan, Qattawi, Omar, 2011], [Witik, Payet, Michaud, Ludwig, 2011]. To conduct an LCA, data and information needs to be collected for analysis, of the cumulative components and services to the end-of-life equipment. Therefore, the implementation of an LCA, due to the complexity and diversity of components and the time frame produces a high number of inputs and outputs to the system which is very costly, time consuming and difficult task [Ameli, Mansour, Ahmadi-Javid, 2016]. Multi-criteria decision-making methods [Mayyas, Shen, Mayyas, Abdelhamid, Shan, Qattawi, Omar, 2011], [Mayyas, Omar, Hayajneh, 2016], [Mayyas, Qattawi, Omar, Shan, 2012a] can develop a variety of methods to apply sustainability considerations with a lifecycle approach for choosing materials and methods of manufacture of the components under review and assessed.

This proposed model uses a cohesive mixed method considering issues simultaneously: component selection, service provided and the EoL options similar to the gray-relational-analysis method, where the choice of the optimal option is in terms of economic, technical, and aspects [Govindan, Shankar, Kannan, 2015], [Hosseinijou, Mansour, Shirazi, 2014], [Jayakrishna, Vinodh, Sanghvi, Deepika, 2016], [Zarandi, Mansour, Hosseinijou, Avazbeigi, 2011].

3.3 Model Formulation

3.3.1 Supply and Distribution

1. Stock
2. Warehouse next day
3. Order

a. Short term (3-5 days)

b. Long term (7-30 days)

4. Need to Manufacture (special order)

3.3.2 The Main Concepts

The parts of the model consist of; Material Type, Fabrication Method, Source/Supply, and Assembly Methods, Then Finally the EoL Decision Process and Options

Materials

1. Metal:

Ferrous

Nonferrous

2. Plastic

3. Ceramic

Each product, has lifecycle steps and each step is depicted in Figure 3.1

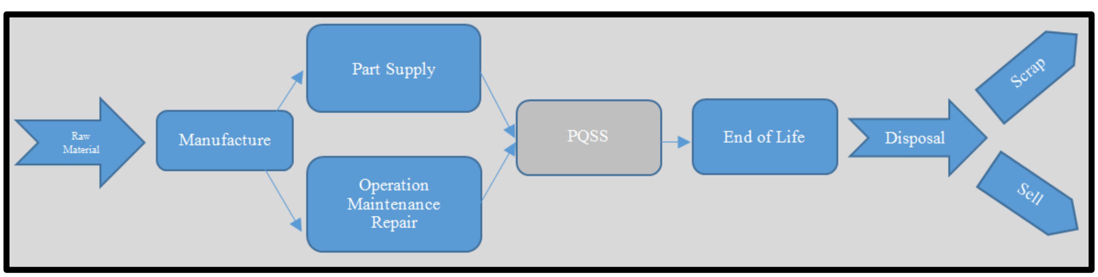


Figure 3.1 Life cycle steps through quality service.

3.3.3 Production Process

The Method of Fabrication of the Specified Components

1. Machining
2. Casting
3. 3D printing
4. other

3.3.4 Assembly

Service Process

1. Manual mechanical
2. Manual electronic
3. Software digital

3.3.5. End of Life

1. Repair
2. Limited use
3. Remanufacturing
4. Disposal
5. Sell: used as is
6. Scrap: Disassembly, Recycle

Therefore, simultaneous reviews of the steps of machine lifecycle for the determination of the level of service is essential. In each step, several factors that strongly influence the performance outcome of type of service conducted. The factors considered in each Step respectively are suppliers, manufacturing, assembly processes and EoL options [Moriarty, 2021b]. The end-of-life step is an important component of equipment life cycle, which is of great interest to many researchers in the area of critical equipment maintenance. End-of-life equipment/machines have a high potential for failure.

In addition, many of these products have large physical dimensions, if not repaired for continued use this space impacts operational resources and not available for productive purposes which then impacts performance.

Sets

B The set of components, index by i,$|B| = n$

G Number of product life cycle steps, index by g, g = 1… 4

M_i The set of possible material choices for component i, index by j, $|M_i| = m_i$, i<- N

P_{ij} The provider of material j for component i, index by u, $|P_i|$ $j = p_{ij}$, i<- N, j<- M_i

C_{ij} The set of components i, for material j, index by t, $|C_i|$ j

= c$_{ij}$, i<- N, j<- Mi

E_{ij} The set of EoL possibilities for component i, under

material j, index by k,

$|E_{ij}| = e_{ij}$, i <-N, j<- M_i

R$_{ij;i'j'}$ The processes attributes (M/R T) for the *service and* assembly of components i material j, along with the component i' of material j', index by a, $|R_{ij};i'j'| = h_{ij;\,i}'j'$, i < N, j < Mi, i, < N, j < M_{i}'

Q_i The set of expected performance of service provided from PQSS program i, index by b, $|Q_i| = q_i$, i 2 N.

Decision variable: binary variables which will equal 0 or 1 respectively

x_{ij} if the material *j* is chosen for component *i,* variable equals 1; otherwise, it equals 0 for this.

y_{iju} if supplier *u* is chosen to supply *j* for component i*,* variable equals 1 otherwise it equals 0.

w_{ijt} if manufacturing process *t* is chosen to produce component *i* of material *j* variable equals 1; otherwise, it equals 0.

$q_{ij;\, i'j';\, a}$ if the assembly process *a* is used to assemble the component *i* of material *j* to the component *i′* of material *j′*; the variable equals 1 otherwise it equals 0.

z_{ijk} *if EoL option k is chosen for component i of material j, the* variable equals 1, otherwise it equals 0.

Parameters

C^T Total product cost over its life cycle

C_g Total product cost at step *g*

C^P *iju* The cost of purchasing material *j* from provider *u* to produce component *i*.

d_{iju} The supplier distance *u* from manufacturer to supply material *j* for component *i*

$C^M{}_{ijt}$ The production component cost *i* from material *j* by manufacturing process *t*.

$C^A{}_{ij;\, i'j';\, a}$ The cost of assembling component *i* of material *j* along with the component *i′* of material *j′*

by assembly process *a _i; i′* If component *i* is assembled into *i′*, the value is one or otherwise it will be zero.

The machine lifetime usage (hours)

C^{R}_{ij} The replacement cost of component *i* from material *j* _*ij* the maintenance and repair frequency of component *i* from material *j* during a product life cycle

Ω The EoL cost

$C^{D}_{ij;\, i'j';\, a}$ The cost of disassembling component *i* of material *j* from component *i′* of material *j′ if* they are assembled by *a* process.

C^{O}_{ijk} The EoL cost if method *k* is used for component *i* from material *j*.

$\omega\ i$ The performance score of component *i*

$\vartheta\ bi$ The importance of performance *b* in component *i*

$\imath\ bij$ The performance score *b* in component *i* if material *j* use

$\lambda\ i$ Minimum acceptable performance for component *i*

μi The importance of component *i* in the product

$\xi\ i$ The Performance Score of total Product

τ Minimum acceptable performance for product.

$\psi i;\ j$ A set of material alternatives that are must be selected at the same time with the alternative *j* of component *i*. *j i; j = I'; j'*

$\phi\ i;\ j$ A set of material alternatives that are cannot to be selected along with the alternative *j* of component *i*.*j* $\varphi i;\ j = \varphi i';\ j'$

3.4 Cost Functions and Analysis

3.4.1. Cost Equations

$$\min C_P = \sum_{g=1}^{B} C_g;\quad g=1\ \text{-.}\ B\ B=1\ldots4\ldots$$

$$\min C_P = \sum_{g=1}^{B} C_g;\quad g=1\ \text{-.}\ B\ B=1\ldots4\ldots \qquad (3.1)$$

C^P Total product cost over its life cycle, C^g Total product cost at Step g

First step: The first step is materials provided relating to available suppliers. The selection of a suitable supplier is the decision variable at this step. For Original Equipment Manufacturers (OEM's), regional transportation and delivery lead time are key in the material selection process.

Consequently, the cost at this step is obtained by the following Equation (3.2).

$$\sum_{i=1}^{n} \sum_{j=1}^{m_I} \sum_{u=1}^{S_{ij}} y_{iju} \left(C^P_{iju} + d_{iju} + C^T_{iju} \times W_{ij}\right) \tag{3.2}$$

Second step: is manufacturing/assembly process: The decision variable at this Step is manufacturing and assembly process selection.

Equation (3.3) represents the component cost.

$$\sum_{i=1}^{n} \sum_{j=1}^{mi} \sum_{t=1}^{pij} w_{iju} \times C^M_{ijt} \tag{3.3}$$

In addition to the production of components the cost of assembling components into the product should be calculated in accordance with equation (3.4).

$$\sum_{i=1}^{n} \sum_{i'=1}^{i-1} \sum_{j=1}^{m_i} \sum_{j'=1}^{m'_i} \sum_{a=1}^{h_{ij,i'j'}} \alpha_{ij} \times q_{ij,\, i'j',} a \times C^A_{ij;i'j';a} \tag{3.4}$$

Third step: operational use, maintenance, and repairs, since the components are not used alone and are assembled together and then the entire CNC machine is used, the costs associated with the use phase should be examined at the product level. In order to assess the cost and impact of this step, first the CNC machine usage should be determined.

According to studies, machine run time has a direct correlation with lifetime span and CNC productivity.

In this study, the runtime equations are (3.4 and 3.5), its value for the CNC machine examined in this paper is,

$$\sum_{i=1}^{n} \sum_{j=1}^{m_i} \sum_{u=1}^{p_{ij}} y_{iju} \left(C^{P}_{iju} + d_{iju} \times C^{T}_{iju} \times W_{ij}\right) \times \eta_{ij} + \qquad (3.5)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m_i} \sum_{u=1}^{p_{ij}} W_{ijt} \times C^{M}_{ijt} + \eta_{iju} \times + \sum_{i=1}^{n} \sum_{j=1}^{m_{i\,j}} \chi_{ijt} \times C^{R}_{ij} \times \eta_{ij} + \Omega \times \eta_{ij} \qquad (3.6)$$

At this step, there is a cost for maintenance and repairs, and it is assumed that the defective component is replaced with the new one.

According to equation 3.6 the cost of maintenance and repair is the total cost of material supply, manufacturing process, replacement and EoL.

Therefore, the CNC machine operation cost is equal to Material supply and production process costs and are calculated in accordance with equations 3.4 and 3.5, respectively and the replacement cost of the components is calculated according to Equation (3.7).

$$\sum_{i=1}^{n} \sum_{j=1}^{mi} \chi_{ijt} \times C^{R}_{ij} \qquad (3.7)$$

The method for calculating EoL cost will be discussed in the next section, equation (3.7) where _*ij* is the frequency of maintenance and repair of component *i* made of material *j* during the CNC machine entire life cycle.

$$\Omega = \sum_{i=1}^{n} \sum_{j=1}^{m_i} \sum_{k=1}^{o_{ij}} w_{ijk} \times C^{O}_{ij} \qquad (3.8)$$

Fourth step: End of life (EoL). The final Step is the management of product EoL, which is an important phase for assessing the service outcomes of CNC equipment / machines. [Ameli, Mansour, Ahmadi-Javid, 2016].

The EoL options investigated in this study are repair for use, rebuild / remanufacture, or disposal (scrap/recycle). In order to reach total EoL, the product must be repairable, completely disassembled for rebuild / remanufacture or scrapped/recycled.

Product EoL and disposal costs are calculated by equation (5) and (6) respectively.

$$\sum_{i=1}^{n} \sum_{i'=1}^{i_{-1}} \sum_{j=1}^{m_i} \sum_{j'=1}^{m'_i} \sum_{a=1}^{h_{ij,i'j'}} \alpha_{ij} \times q_{ij,i'j',}a \times C^{D}_{ij;i'j';a} \qquad (3.9)$$

3.4.2 Cost Review

The Cost Associated with Assembly, Setup, and Overhead Functions:

This includes element component subassembly variants of part design configuration, and the usage of new, reused, and/or refurbished component parts made from recycled materials and the cost of collecting these parts, may also be considered when assessing EoL products. Hence, the objective function is shown below [Aydina, Brown, Badurdeena, Lia, Roucha, Jawahira, 2018].

Cost objective function.

By summation of the above four mentioned costs, the overall cost function is obtained, and the objective is to minimize the overall cost.

Various other constraints related to raw materials, production methods, resource availability, production capacity, etc., could be relevant, dependent upon the specific product and manufacturer considered during the quantified service optimization configuration process. Such constraints would need to be included on a case-by-case basis when preparing the constraints of the specific situation [Bi, Zuo, Tao, Liao, Liu, 2017], Solving the multi-objective optimization problem is an evolutionary process and has been utilized in research and many other studies. Algorithms of this nature are capable of reducing computational difficulty and providing an effective method of handling constraints, which makes it an efficient method of solving for multi-objective optimization [Badurdeen, Aydin, Brown , 2018].

3.4.3 Design and Management Cost Impacts

The service cost is reverted to an original cost and added to the cost of the original machine cost and then a percentage of ownership cost is computed. This method is an original means of associating the cost of ownership with the overall cost of the equipment. This is done by calculating the present value equivalent of this cost, the value generated from this service analysis in the research. This present value is based upon a general 3% cost of inflation (i) over the same time period (lifetime of the equipment = n) on an annual basis, e.g.,

cost value of service analysis * $(1+ i)^{\text{service lifetime}}$, $\text{cost}(1+.03)^{-n}$.

This example displays the detailed aspects of this analysis using the following information: the machine installation date of Feb 15th, 2015, a maintenance service date of Dec 15th, 2019, an interest rate of 3%, a machine installation price or $375,000, and a maintenance cost of $5,000. As seen from this analysis.

Added Cost = $\$5000\ (1+0.03)^{-3.9}$

Table 3.2 Research Index Value Example.

Description	Value
Index Value	96
Maintenance Cost	$5000

Table 3.3 Analysis of Cost.

Description	Value
Percentage or	
Installed cost	1.2%
Present Cost	$4,455
Installed date	2/10/2015
Service date	12/18/2018
Interest	3%
Price	$375,000
Maintenance Cost	$5,000

3.5 Description of the Mathematical Model Constraints

3.5.1 The Performance of Each Component

Is Multiplied by Its Importance and the Total Product Function is Obtained. [Ameli, Mansour, Ahmadi-Javid, 2016].

$$\sum_{b=1}^{q} \sum_{j=1}^{m_i} \chi_{ij} \times \vartheta_{ij} \times \imath_{bij} > \lambda_{ij} T_{\mathrm{i}} \qquad (3.10)$$

$$\sum_{i=1}^{n} \mu_{ij} \times \omega_{bij} > \tau \qquad (3.11)$$

$$\sum_{j=1}^{m_i} \chi_{ij} = 1 \quad T_{\mathrm{i}},\ j\ (j < m_i) \tag{3.12}$$

$$\sum_{u=1}^{s_{ij}} Y_{iju} = \chi_{ij} \quad T_{\mathrm{i}},\ j\ (j < m_i) \tag{3.13}$$

$$\sum_{t=1}^{p_{ij}} \upsilon_{ijt} = \chi_{ij} \quad T_{\mathrm{i}},\ j\ (j < m_i) \tag{3.14}$$

$$\sum_{k=1}^{o_{ij}} Z_{ijt} = \chi_{ij} \quad T_{\mathrm{i}},\ j\ (j < m_i) \tag{3.154}$$

[Ameli, et al., 2016].

Constraints 3.10 to 3.15 ensure that each selected component is made up of only one material, and has one supplier, one production/assembly process and only one EoL option.

3.5.2 Solving the Model

In this research, categories of components investigated: The drive motor of the machine (includes 4 key components), closures and safety controls (6, including main panels), slides, ways, and holding devices (including 6 components) and electronics (8 components), therefore, for purposes of this paper a total of 24 components have be utilized to examine the functional model.

Material alternatives for components in this study are classified into 6 general categories: steels, high strength steels, stainless steel, aluminum, and composites such as: (standard plastics, fiber glass reinforced plastic and carbon fiber-reinforced plastic). Material choice can be problematical for an engineer, particularly when the material is being used in an application for the first time. The process of material selection for this research supports the design engineering role during the early and design steps of product development.

For durable material selection, tradeoffs between economic, life cycle, and technical requirements for each component are identified and ranked. In the proposed model, the technical criteria are considered as constraints, as explained in the previous section. A list of some of the major components used in this analysis are shown in the conclusion of this research. The technical criteria and the score of each sub-function is extracted from [Mayyas, Shen, Mayyas, Abdelhamid, Shan, Qattawi, Omar, 2011], [Mayyas, Omar, Hayajneh, 2016], [Green, 2018].

To calculate impacts, performing a comprehensive life cycle assessment is very complex, time-consuming, costly, and requires a wide range of data. Therefore, in this paper, EoL is used as the measure of the product productivity [Ameli et al., 2016] used as a gauge to quantify the productivity impact of a given data set for CNC service maintenance.

This developed model is a multi-objective linear model. An increase in the number of components, which increases the alternatives of the materials, will therefore increase the complexity of the model which then increases exponentially. If we assume a machine has only 4 components and for each component there are 3 material alternatives, each of the material alternatives has at least two suppliers, for each material, at two different means of production and assembly are available and each of these alternatives have the four EoL options. Therefore, there will be 3^4 x 2^4 x 2^4 x 4^4 or 5,308,416 alternatives to select. Adding only one component (3^5 x 2^5 x 2^5 x 4^5) will increase the number of options to 254,803,968, This demonstrates the challenge and magnitude of this enormous task of selecting the best configuration. and while the developed model provides CNC machine tool manufacturers, and service providers and maintenance providers the means of selecting optimal alternatives in a reasonably short time period. While there may be no optimal answer to this type of multi-objective problem, a successful (or optimal) pareto solution is are achievable for these problems [Steuer, Piercy, 2005]. A multi-objective decision problem could also be introduced to follow digital -twin approach for product in the smart manufacturing environment [Zheng, Sivabalan, 2020].

3.6 Chapter Summary

In this paper, an approach was developed utilizing integer programming to select key alternatives (e.g., material) and optimize CNC machines configuration of components, composed of large number of components. This method of option determination analysis utilizes a number of attributes: material selection, supplier selection, manufacturing process selection, assembly process selection and EoL for components of a CNC machine are integrated and solved simultaneously [Moriarty, 2021b]. The purpose of this model is to minimize producer costs as well as impacts throughout the product life cycle so that the technical and production constraints of the CNC machine are also considered. In order to validate the proposed model, a simulation study was conducted in on vital CNC machine components identified as significant to the CNC service industry. For this purpose, the following general machine component categories have been investigated, (a total of 25 items):

1. enclosure, doors, and safety controls of the machine (6 components),
2. drive motors (4 main drives),
3. frame, slides, ways and holding devices (6 components)
4. electronics and sensors (8 component),
5. lastly software upgrades.

In addition, sensitivity analysis was conducted to evaluate the effect of CNC machine run time on impact and cost. The results show that by reducing runtime the impact upon the CNC machine is also reduced, while the total cost increased. Since, in the proposed model, the product runtime rates and technical functions are considered as constraints, the over-reduction of the CNC machine runtime is in direct conflict with these two constraints and is not feasible; because under use of the CNC machine significantly reduces the output rate of the machine and does not meet the expected performance and productivity of the research.

3.7 Research Innovations

The concept of reliable component, service and maintenance has concerned maintenance and quality researchers for decades. The development of reliable quality maintenance and production one of the concepts that is a requirement for quantitative tools of measuring and decision making.

While the cost analysis in the example conducted was a sample of just on service incident, the fully functioning simulation uses both individual scenarios of the key components listed as well as the C^T Cost analysis value to determine the overall cost value and percentage. This value is then converted into a specific "Index Value" (IV) for the specific machine and/or application site. Given an allowable site value between 0.0% and max 30% for the example e.g., 1.2% this IV = 96.0. This index value represents the acceptability score of this service based upon 0 - 100 value. Therefore, this example is 96/100 acceptable cost ration IV=96.0. To achieve this, it is essential to review the methods of selecting key component and service attributes, such as material. The innovation of this methodology of both material selection and quantitative service development approach integrates EoL considerations into the decision process [Moriarty, 2021b].

The consideration of supplier, manufacturing, assembly process and EoL options variables during the process of optimal selection are key factors. Reliability, health, and safety requirements in material selection are also key considerations. Additionally, the consideration of technical requirements in reliability of the key attributes process selection is also fundamental.

A recommended future direction is to consider the social sustainability attributes in the process of selecting sustainable materials and providing a method for their evaluation. Another interesting future research area is in modelling; consider uncertainty in the proposed mathematical model, may be to use a deterministic model of programming at the appropriate steps in the process. Considering the objective functions of this model versus another optimizing model, could create another kind of problem-solving method in this research field. For example, a goal seek type programming method might be used.

CHAPTER 4

THE M/R T TRANSFORM

Chapter 4 describes the Transform to better integrate existing mathematic models.

4.1 Basic Understanding of Modular Transforms

The components of the transform function are a weighted portion of more specific attributes which have been identified to be specific to the CNC machining centers functioning engineered system. In addition, the mathematic models for these attributes are a distinctive to this engineered system.

The last aspect of this PQSS system proposal is to limit the attributes applied to the M/R T function. These attributes are exclusive to the application of this technique to the engineered system of machining centers. This step equates to a reduction / limitation of the attribute "Key Predictive Attribute" (KPA) metrics applied to the overall aspects of this research.

The overall objective of this transform function is to develop a service system which predicts the expected outcome of the machine service provided by the service department to minimize the overall down time of the equipment.

QSQ Quantitative Service Index (QSI) = (derived from the simulation).

"In mathematics, the study and the essence of transform theory is that by a suitable choice of basis for a vector space a problem may be simplified—or diagonalized". Computer tools such as Micro Soft Excel, Minitab, R, and others to be determined (TBD)

4.2 Basic Understanding of Moriarty/Ranky Transform Functionality

The concept of Appling KPAs to this transform is an advancement to the body of knowledge of machine service maintenance. The KPAs have been chosen based upon the research data extracted from two years of information acquired from CNC machines. Each KPA has a unique equation associated with the particular attribute which has been created to quantify an attribute index value for the KPA. Then a weighted value is generated from the statistical distribution of the simulation data. This is then applied to the M/R T function to generate the QSI score for this machine Maintenance service.

4.3 Specific Aspects of the M/R T Function.

PQSS Quantitative Service Index =

$$i = \sum \ (\mathrm{W1A1} + \mathrm{W2A2} + \mathrm{W3A3} + \cdots + \mathrm{WiAi}) \qquad (4.1)$$

(A1+A2+A3+A4+…+Ai)

$(W_{1.1} + W_{1.2} + W_{1.3} + \quad + W_{i.j})$

$(W_1A_1 + W_2A_2 + W_3A_3 + \ldots + W_iA_i)$

W_1*Experience performance , W_{2*}Forecast, W_1*Service Life, …, …

4.4 M/R T Simulation.

After a full investigation of several available simulation packages available (see list below) the package of choice is SIMIO, based upon the strengths of integration, modeling, and functionality with manufacturing and distribution systems. Excel is the tool used for this functionality currently.

Simulation systems available and reviewed for future robust system abilities: SIMIO, ARENA, AnyLogic, FlexSim, Anylogic, Minsky, SimScale, Sim3D.

4.4.1 Research Design Objectives and Approach

Interpretation of results and represent and/or indicate.

Chapter four reports the results of the simulation on the resultant version.

“In mathematics, the study and the essence of transform theory is that by a suitable choice of basis for a vector space a problem may be simplified — or diagonalized”.

Computer tools such as Micro Soft Excel, Minitab, R, and others to be determined (TBD).

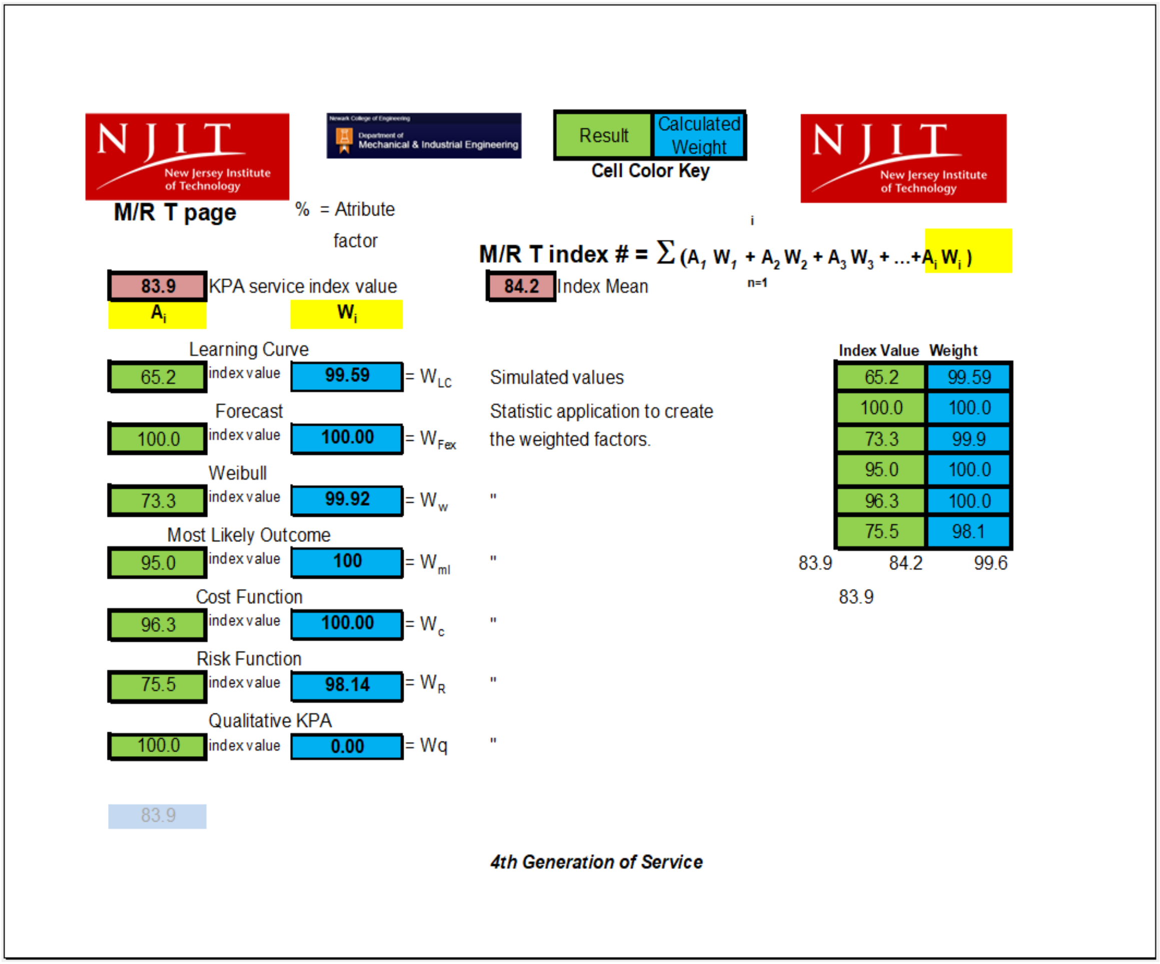


Figure 4.1 M/R T results page.

4.4.2 Simulation Report / Results

The validation of this research is incorporated into the results of the simulation. The simulation file generates an index value for each KPA individually and then creates a simulated weight factor from the distribution of the data distribution. These factors are then incorporated into the M/R T function to calculate the QSI value which is then used as the standard for expected service outcome of the maintenance to be performed.

4.5 Patent Information

PQSS - QSQ Firmware Product Controlling Integrated System in a Computer Network. The QSQ product is embedded in firmware in the format of a USB stick, or a chip (see below) to control the integrated CNC machine or system of machines in a network. The QSQ firmware product can also be integrated with a cell controller (see below) to control a computer network of complex engineered systems, e.g., CNC machining centers, Mills and Lathes, Robotic surgical systems, computer controlled advanced domestic appliances, aero / jet engines, etc.

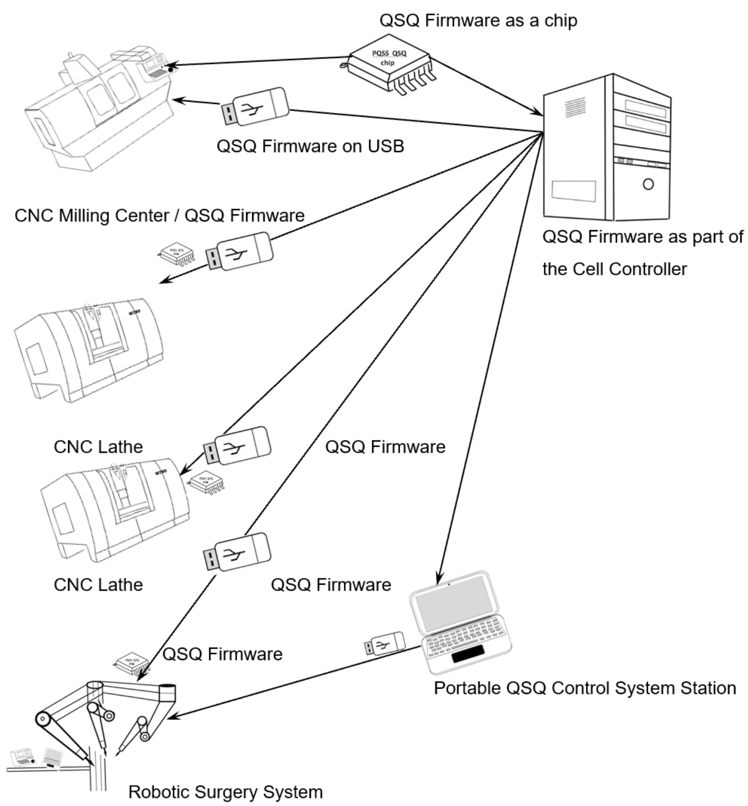


Figure 4.2 Patent firmware diagram.

Integrated Circuitry Schematic:

This proprietary system will additionally interface with machine systems through a uniquely modified electronic circuit to collect data, process the M/R T transform and communicate with the machine, processor, program, and maintenance operators, / machine operators.

The schematic displayed below displays the circuitry utilized by this algorithm and the program to run this unique process. Basically, this connectivity is the USB connection used to transfer data between the processor, storage device and the program to run the Predictive Quantifiable Service System. Output is communicated currently proposed through RS485 via an RJ45 type connection. LEDs are incorporated to display the progress and activity. The basic circuitry of this process can be created through the use of an integrated circuit which is then modified for PQSS M/R T purposes

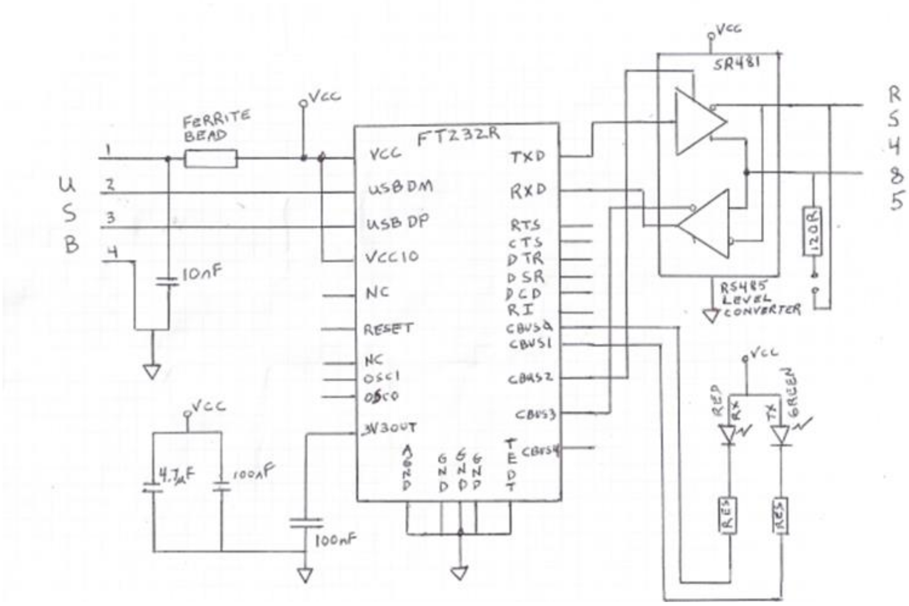


Figure 4.3 Patent schematic

CHAPTER 5

QUALITATIVE KPAs

Computer Numeric Control (CNC) machine service and maintenance requires additional capabilities, related to providing quality service. Extensive research has been conducted on the subject of preventive, predictive and corrective maintenance over the years. While manufacturing companies possess quality capabilities for product development and production, quality service requires a different set of operational capabilities. This raises a unique research question, which is to identify unique Key Predictive Attributes (KPAs) of CNC machines and determine if these unique KPAs are significant to the quality service process. Further analysis identifies the consequential impact these predictive attributes will have upon the projected outcome of quality service maintenance.

The results are quantifiable and support a dynamic scenario analysis with value adjustments to regulate the predicted result. Quality service-oriented capabilities are necessary to successfully generate a Quantitative Service Quality program. These areas of previous research have focused on the general maintenance capabilities and not the successful quality outcome of the service, which demonstrates this research is original, distinctive, and innovative.

There are three basic manufacturing revenue streams, Product Delivery which is the most predominant revenue generator for a manufacturing company. This is why manufacturing companies are in business, to sell the products they make. When the product ships it is not part of the manufacturers business process and also typically no longer part of the revenue flow. This takes us to the next step in the revenue flow, Post Sales service, maintenance, and repair. This function can provide continued revenue for manufacturer, in the form of product maintenance. Finally, adopting the development of Enhanced Services provided to customers after the sale of the product. This takes revenue generation to another level. Enhanced services tend to be more focused on creating value for the customer by maximizing service and building relationships. In many cases, enhanced services may be based upon a service contract basis, where fees are based upon service outcomes and not labor hours or material usage. Furthermore, currently there is inadequate data and information for a manufacturing company to recognize and quantify the necessary Key Performance Indicators to establish the necessary capabilities and plan the corresponding development of a high-quality Quantifiable Service Quality system.

Through the development of qualitative and quantitative Key Predictive Attributes (KPAs) this research answers the operative question of predicting Quantitative Service Quality with a system-oriented approach to generate a best-case rating scheme for CNC machine maintenance service. This formulation of a quantifiable service process performs an analysis of product attributes that leads to the prediction of expected successful quality performance of the maintenance service provided.

This process further drives the creation of service-oriented strategies for manufacturing companies to implement and perform service as a continuing revenue stream. This includes product attributes and corresponding service capabilities. Finally, the application and functional usage of a proposed process of quantifiable service quality within CNC machining operations is illustrated through the formulation of quality service strategies of manufacturing companies and the system.

The quantitative mathematical functions of this research are as follows, Experience Performance Factor equation and application. Utilizing a min percentage (α), a max percentage (β), and a most likely percentage (χ) are utilized to generate the experience factor percentage (Γ), therefore, $\Psi_{\Gamma} = (\alpha\Gamma^{\beta})\ \eta$

Service Value created a unique method of assigning asset service cost through an equation and evaluation process indexing service evaluation.

$SV = \eta - (\eta\ [C(1+i)^{t} / P] / \upsilon)$

Risk Function assessment program created a Graded Likely Risk model application to CNC service. A Graded Risk Process has been created.

Methods researched.

Data Mining (DM)

Multi-Criteria Decision Making (MCDM)

Mixed Integer Non-Linear (MINL)

Mixed Integer Linear (MIL)

Best Worst Method (BWM)

Analytical Hierarchy Process (AHP)

Delta Sum created forecasting calculation. Delta Sum Method (DSM)

This forecasting method introduces a delta “Δ”, factor and applies 50% of the delta difference result to additionally balance out the projected numerical result.

$F_{\Delta\Sigma}$= (1- λ)(Last Service) + 0.5Δ + λ(Last Estimate)

Service Life component produced new multi-dimensional functions for reliability evaluation. Service organization models a repair or part replacement for service. Several service calls are recorded. A comparison of allocated variable value vs actual variable value delta is then tabulated in the simulation register for multiple services.

$F(sl) = [1 - \exp(sl - \alpha / \beta)]\ \eta$

Qualitative attribute KPAs. Created an indexing function to quantify ten (10) identified Qualitative attribute KPAs to assigned a Quantitative value to these KPAs.

$KPA_q = (M_xV - \overline{X}_{sim}) / \overline{X}_{sim}\ \eta$

Most Likely is a created outcome index function. This factor takes the mean of all KPAs upper and lower simulated values. A sample of random values assigned a tolerance factor is then generated. The mean of these two functions is created in the simulation table to create this quantitative value.

Simulation A_{ml} = Mean $(\Sigma \overline{X}, \overline{X}')$

5.1 Basics of Qualitative Key Predictive Attributes

With the considerable challenges associated with service markets this is driving CNC machine tool manufacturers to seek different methods and techniques of providing machine service in an integrated manner to improve customer value and thereby increase revenue. A fundamental aspect of this function has long been the application of Key Performance Indicators (KPIs). This research introduces a unique application of the crucial role of qualitative Key Predictive Attributes (KPAs) play in this original application of an assessment method using (KPAs) are identified and applied in the quantification and prediction of quality service.

This fundamental modification to the traditional service industry emerges as a new strategy to provide a fourth dimension to providing machine maintenance service. This unique concept is associated with service providers altering their strategy to reposition themselves within their customers' value stream.

It signifies a change in the scope and type service offerings due to the orientation shift from a labor and material-based maintenance model to a customer-centric or service-based operational standard [Brax, Visintin, 2016], [Martinez, Neely, Velu, Leinster-Evans, Bisessar, 2016]. [Cavalieri, Pezzotta, 2012], [Alghisi, Saccani, 2015], [Benedettini, Neely, Swink, 2015], [Nudurupati, Lascelles, Wright, Yip, 2016], [Zhang, Banerji, 2017].

Appling Quantifiable Service Quality is a complex process and successful outcomes are never guaranteed. The implementation of service maintenance change is both inevitable and necessary if service functions are to improve the overall financial value to customers and/or organizations, [Brax, 2005], [Gebauer, Fleisch, Friedli, 2005], [Lee, Yoo, Kim, 2016]. Undesirable outcomes, widely recognized as "service paradox", are linked to poor strategic planning and implementation of service quality [Fang, Palmatier, Steenkamp, 2008], [Kohtamäki, Partanen, Parida, Wincent, 2013], [Kastalli, Van Looy, 2013], [Rabetino, Kohtamäki, Gebauer, 2017]. This is a major reason, why many researchers have to a great extent, focused on the discussion of how maintenance companies and machine tool suppliers can achieve a successful customer service platform, [Oliva, Kallenberg, 2003], [Paiola, Saccani, Perona, Gebauer, 2013], [Storbacka, 2011], [Ulaga, Reinartz, 2011].

5.2 Financial:

“Value-Based Pricing”: Pricing based upon value is a process by which goods or services are priced according to the value the customer places on its perceived value the product or service brings to the customer. Value pricing is based upon focusing on the worth to the company, [Kindström, Kowalkowski, 2014].

How much a company is willing to pay for products or services provided is the process of pricing based upon value to the customer. This is basically the customers perceived value the goods or services will bring to their organization. Customer-oriented pricing on the other hand represents the company's pricing strategy is centered around the value they believe customers consider the product has to their organization. Simply put this is the price they are prepared to pay for goods and services. In the competition for CNC machine tool service, reputation and service quality determine the value that the service company can demand.

There is a difference between pricing based upon benefit worth and "cost plus" where production costs are incorporated in the pricing result. This is reflected in many CNC machine tool manufacturers through the offering of service contracts based upon the initial total purchase cost of CNC machine tools. Companies that provide unique functionality or exceptionally valuable services are liable to employ value pricing models more than companies that sell commodity type goods or services.

Regarding the quality of service of CNC machine tools, the key points are:

• Value-based pricing is a CNC machine tool service strategy in which the maintenance / service / repair price is determined based on a consumer's perceived value of related goods or services.

• Pricing based on worth to the company is a customer-focused pricing strategy. This means that the company's pricing is based on the customer's estimation of the worth of the product to the overall organization, it's contribution to the bottom/top line.

Understanding Value-Based Pricing and How We Can Quantify Such Pricing. The principle of pricing based upon value predominately addresses markets in areas where the customer perceives the use or implementation of the goods or services will benefit or improve their overall organization, by increasing productivity or revenue. They also carefully analyze competitors' prices and service offerings. For this reason, perceived value is an indication of value of the goods or services a customer is willing to place upon the products and therefore has a direct impact on the final price the customer pays.

Although pricing is an inaccurate science, marketing research methods and techniques can be used to determine pricing. For example, CNC machine tool distributers / manufacturers normally ask for customer feedback to more realistically quantify the customer-perceived value of the purchase/expense guiding them to a particular CNC model. They also carefully analyze competitor prices and service products. Therefore, the seller can determine the service price of CNC machine tools using the value-based pricing method.

Features required for Value-Based Pricing Any business that practices value-based pricing must have certain goods or services which set them apart from their competitors. The same applies to CNC machine tool manufacturers. Products must be customer-centric, which means that all enhancements and advanced qualities should be based on customer needs and expectations. If an organization looks to pursue a pricing strategy of add assessed worth at its focus, the product or service must be perceived of having superior features and quality. The company must have a close relationship, open communication channels and be partnered with their customers throughout this process. This allows CNC machine tool builders / distributors to get feedback from their customers on the special features they are looking for and how much they are willing to pay.

5.3 Customer

Customer (technical) intimacy: In terms of CNC service quality, we can identify the following types of technical intimacy, [Parida, Sjödin, Wincent, Kohtamäki, 2014].

• emotional (e.g., the CNC quality service technician must stay calm and professional, even in stressful situations, when something does not go well during the servicing process; like further issues are detected and the reasons for downtime jump exponentially).

• mental (e.g., the CNC quality service technician must be prepared mentally for all kinds of technical challenges during the maintenance / service process).

• systems view (e.g., the CNC quality service technician must accept a system engineering view, meaning, that cause-and-effect chains might have to be investigated and any issue with such complex electro-mechanical / hydraulic / pneumatic machines must be viewed as part of the entire system, like a human body and soul! Not just a single organ, like a CNC machine's drive, but the power supply to that drive (i.e., organ), the lubrication, load, control, etc. of that drive to within the entire CNC system), and physical (e.g., appearance, punctuality, behavior, listening skills, communication skills, documentation skills, politeness, firmness, business like behavior).

Value co-creation with customer: Co-creation of value is a business strategy, one that promotes and encourages active involvement from the customer to create on-demand and made-to-order products. With co-creation, consumers get exactly what they want (we can use a checklist here to quantify the outcome of this test / analysis: what do CNC customers want from a repair / maintenance process?) and have a hand in making it happen.

5.3.1 Internal Processes

Close collaboration with partners: Collaboration is a functional method of individuals work together for a mutual purpose to achieve economic gain. The practice of collaborating allows the team to work together to accomplish a particular and collective organizational goal. [Story, Raddats, Burton, Zolkiewski, Baines, 2017). The key here, for each CNC machine service task is to identify the realistic objectives and the predictable outcomes of the service process.

Service-oriented personnel: All in all, customer service-oriented personnel are those who are able to listen, ask all the right questions, clarify everything that is unclear, and respond to every realistic (meaning previously taught / experienced) challenge promptly, [Paiola, Saccani, Perona, Gebauer, 2013]. It is also crucial for CNC machine related employees have a deep knowledge of the product or service. A CNC machine is a complex device, service should be considered to be a health check process too (just like an annual med. check for a human being). Service-oriented Information and Communication Technologies (ICT) include learning and growth steps in the process. It must also incorporate a service-oriented performance measurement system. A customer service-oriented culture means, that a company focuses on its customers (e.g., measurables include response time, speed of resolution), their requirements (e.g., a ranked requirement list and a ranked solutions list compared and rated, see QFD as a good method here), and needs (requirements = needs). [Gebauer, Paiola, Edvardsson, 2012]. When a company values their customers above all else, they respond customer needs quickly, effectively, and efficiently, this is known as service-oriented performance. CNC machine service performance is a matter of making sure, that the processes are performing according to the specifications (e.g., specs should be a weighted list of measurables).

To developers, service performance is a matter of making sure that the functional requirements are being met. Functional requirements define the basic system behavior of a CNC machine following normal (meaning within tolerance limits) operations. This is principally, what the system does or what it must not do. It can be interpreted as how the system responds to operator or controller automated inputs. Functional requirements usually include computations, data input, with defined statements or behaviors (egg, if/then) and operational processes. (Again, weighted lists should be compared to quantify / evaluate this attribute.) A functional requirement describes what a CNC service technician should do, while non-functional requirements place constraints on how the system will do so. A functional requirement example would be, a system must perform a specific task whenever a particular condition is met (e.g., the stop button is pressed, the tool must return to home position, etc.).

Typical functional requirements may include:

- Business Rules.
- Transaction corrections, adjustments, and cancellations.
- Administrative functions.
- Authentication.
- Authorization levels.
- Audit Tracking.
- External Interfaces.
- Certification Requirements.

Product service culture: service culture is an organizational culture where there is a collective set of agreed rules employees think about providing outstanding service (egg, survey results), act to provide it, and understand how and why they do it.

A generic definition of a service culture is one where employees are obsessed with customer service. Excellent customer service has four key qualities:

1. personalized (matching two lists: requirements list, solutions list),
2. competent (problems resolved? How many?),
3. convenient (i.e., easy to call / arrange service, service done fast, at low / acceptable cost, acceptable results),
4. proactive (e.g., preventive maintenance, automated condition monitoring / reporting / analysis / action planning).

To be competent, a customer support professional must have a strong intimate technical knowledge of the company and its products, as well as has the ability and authority to fix the customer's problems.

5.4 The Organizational Change

Standard Labor and Material Services to Value Creation Service.

Capabilities of a qualitative KPA Driven QSQ Service organization.

Real time data availability.

Customer service-oriented business focus.

5.5. Research Method

The following are characteristics and traits (KPAs) of customer service excellence applied to this research and CNC machine service:

5.5.1 KPA Functional Look Up Tables

1. Emotional Intelligence
2. Technical knowledge
3. Active listening and communication skills
4. Multitasking abilities
5. Time management skills
6. Prioritizing tasks
7. Positive attitude
8. Being organized and structured
9. Problem solving
10. Rapid response and swift service

5.5.2 CNC Service Quality Examples

OKUMA: accessed on April 17, 2020, https://www.okuma.com/blog/handy-checklist-for-preventive-maintenance

HAAS: accessed on April 17, 2020, https://www.haascnc.com/HFO/HFO-Haas_Factory_Outlet/Preventive-Maintenance.html

FANUC: accessed on April 17, 2020 ,
https://www.fanucamerica.com/support/cnc/service-contracts
https://www.fanucamerica.com/support/cnc/technical-help

5.5.1 Service Organizational Considerations

Internal steps of contextual data simulation:

Contextual data is the background information that provides a broader understanding of an event, person, or item, [Barney, 1991]. Simulations can involve physical materials (drawing items from a bag, tossing coins, sampling candies) or involve generating data on the computer (drawing samples from a population or generating data based on a probability model). The Unified Modeling Language as used in systems engineering defines a context model as the physical scope of the system being designed, which could include the user as well as the environment and other actors. A context model can also apply to the surrounding elements in a gene sequence. Something contextual relies on its context or setting to make sense. If someone asks you what contextual reason you have for choosing an answer after reading a chapter, for example, you will have an opinion in the context of what you read — it is contextual because it came out of the text. A context diagram, (or “level 0 data-flow diagram”) will effectively describe and identify the key factors of the simulation. This process identifies the flows of information flows linking external entities with the system. This enables us to fully depict the whole system in on single process

The process of making a context diagram

1. Select the “Data Flow” shape library or choose a template.
2. Place your system in the center of your context diagram.
3. Add all external entities around your system.
4. Add and specify data flows between your system and external entities.
5. The team members and stakeholders need access to the system.

Simple steps to draw a data flow diagram online with Lucid chart.

1. Create a model of the data flow diagram.
2. Identify diagram of the data flow diagram title.
3. Add an external entity that starts the process.
4. Add a Process to the DFD.
5. Add a data store to the diagram.
6. Continue to add items to the DFD.
7. Input details and data to the DFD
8. Create a data flow name.

Step 2 Context simulation analysis:

Simulation method of Analysis is a process where a great number of computer calculations are performed to achieve the best possible outcome and probability of a selected activity.

The concept of simulation analysis can be further comprehended through the following steps: The first step is to model the project and the answer to this is a simulation analysis. In CAD, simulation analysis is the process of developing a mathematical representation of an actual or proposed product in a computer model. Engineers often simulate thermal, modal, and structural properties of models.

Steps of a Simulation analysis.

1. Prepare a problem statement.
2. Determine the variables and construct the items for the simulation.
3 Identify the decision variables and the constraints associate with them.
4.Assign the constraints to the simulation.
5. Identify the output variables.

There are several different simulations from which an organization may choose from.

- Strategic simulations involve the strategic management of the business.
- Business appreciation.
- Tactical management.
- Totality simulation.
- Functional Simulations.
- Concepts Simulations.
- Planning Simulations.
- Process Simulations.

For the purposes of this research a Functional Simulation will be utilized.

The steps of the Simulation steps:

- Step 1: decide on the purpose of the simulation and what performance metrics you want to monitor. Very rarely will is it necessary to simulate the entire business.
- Step 2: Build a first Pass Simulation.
- Step 3: Calibrate Your Simulation.
- Step 4: Analyze the Results and Select the Best Alternative.
- Step 5: Share Your Simulations.

External Context

- Step 1 Contextual data simulation [Paton, McCalman, 2008].

• Step 2 Context simulation analysis [Osterwalder, Pigneur, 2010].

5.6 The Application of Proposed Method

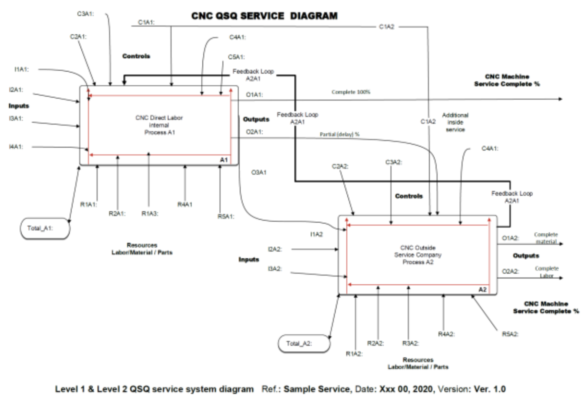


Figure 5.1 Generic system data flow diagram

5.6.1 Phase 2 – The Validation of the Proposed Method

The validation of this step in the predictive quantifiable service quality process is done in the simulation system developed and references as “QSQ M/R T” system (patent pending). This process generates the data from the generic input of the required maintenance. The data is then simulated within the system, and a statistical analysis of the information is generated. This is then quantified by the system and normalized for the generation of a format necessary to be incorporated into the System Index Value criteria.

5.7 Simulation Development and Application Results

The key areas of this research have resulted in several new concepts and content as well as the creation of Key Predictive Attributes; risk assessment, “Service Risk”, service life cycle, service value, experience performance factor, and a delta sum forecasting method. These items have been investigated and quantitative equations to assess these key components have been created.

The methodology utilized to assess and simulate this process creates a unique index value for each KPAs unique equation and applies a weighted factor from the distribution statistical data utilized in the simulation. This is then incorporated into the Moriarty Ranky Transform or M/R T algorithm. This transform takes the mean summation of all the KPAs to create a general quantified indexed the outcome of this service is a methodology unique to the prediction of service outcome and takes machine service to the next level designated as maintenance 4.1 in the Industrial Internet of Things (IIoT).

This research has created the concept of KPAs, created equations to apply to them, and created the M/R T algorithm, The process and system is validated via the simulation model uniquely created for this research.

In addition to this unique method created, an application of firmware, integrated circuitry, and the algorithm, are used to implement this system into the equipment, via computer link, a USB drive and ultimately an integrated chip within the equipment. This method and system is modular and can be expanded to any number of multiple variables. The system therefore can be used for simulation of the process or actual real time service data.

5.8 Value Creation Service as a Business Driver

In addition to internal conditions, external factors within the organization specific situation circumstances will have an influence on the effectiveness of the organizational, [Paton, McCalman, 2008].

External context refers to these forces beyond the organization sphere of influence and control. This may shape the industry competition (of the company) and affect organizational decisions. External forces may include trends or event in the marketplace as well. The business must add to an environment framework, [Osterwalder, Pigneur, 2010], to identify these external elements denoting the external context of service-oriented business model. Among these concepts, service-oriented business and PSS are terms the commonly used describing this experience, [Rabetino, Harmsen, Kohtamäki, Sihvonen, 2018]. The PSS concept has developed from different research viewpoints and communities, [Lightfoot, Gebauer, 2011]. One is PSS research focuses on development and implementation of the products and services and the other is as a bundled offering to provide high value, [Tukker, Tischner, 2006], [Sakao, Shimomura, 2006], [Datta, Roy, 2010], [Meier, Roy, Seliger, 2010].

5.9 Necessary Capabilities for Service Value Creation

The required capabilities should utilize a holistic approach which provides a comprehensive organized understanding of the company's value creation, [Kaplan, Norton, 2000]. This will generate a clear understanding of how the capabilities and their interconnectivity across activities throughout the organization. This assists the organization in the implementation of service value creation. This creates a logical frame of reference for the development of necessary cross functions capabilities of the company when implementing a value creation service system. There are four strategic points of service value creation, “Financial, Customer, Internal Processes, and Learning and Growth”, [Sholihah, Maezono, Mitake, Shimomura, 2019]. These are necessary capabilities across the organization for a successful system. These four points are the context from which the qualitative KPAs are generated for the M/R T simulation lookup table and statistical analysis.

5.10 Chapter Review

This part of the research support how the tool and KPAs support the strategic plan of an organization service as a business driver, and how the company can focus on the capabilities for successful service through quantitative methods. This research helps contributes to the concept of Maintenance 4.0 and the 4th generation OF Machine Service. The context of CNC service identifying factors of internal and external context comprehensively. This was accomplished through quantifying the qualitative characteristic of providing exceptional service capabilities necessary for successful implementation of this quantitative system. The aspects of the business environment (external context) conceptualization for this part of the research may be directly adopted to the general process of change management theory to adopt this PQSS concept within an organization, [Baines, Bigdeli, Bustinza, Shi, Baldwin, Ridgway, 2020], [Bigdeli, Baines, Bustinza, Shi, 2017] . In addition, this research contributes to the continued literature by of CNC maintenance and service. The outcome of this investigation and creation of this tool is significant to the quantification of service outcome prediction significantly contributing to the area of highly engineered system service. In particular, this section identifies and quantifies qualitative attributes of the process.

This has successfully put KP's in context and at the forefront of the analysis in the formulation of service-oriented strategies for service as a business and revenue stream as well as the customer satisfaction service. This resulting method enables manufacturing companies to plan strategic for solid and rationally quantitative service system implementation. The current literature, generally speaking, current literature does not address this approach of using quantified KPAs or quantified qualitative KPAs as guidelines or capabilities of predicting service outcomes. Qualitative service factors can be ad hoc, anecdotal and/or heuristic in nature. All of the previously methods can be quantified utilizing this tool created as a result of this research.

CHAPTER 6

USABILITY TEST AND MODIFICATIONS OF THE TOOL

These three sections describe the usability test and modifications of the tool.

6.1 Details of CNC Machining Centers

CNC machining centers are highly engineered equipment requiring routine service preventive maintenance and predicted maintenance . Maintaining this equipment requires a great deal of skill and training. High quality maintenance also requires a great deal of experience. The technicians must be highly trained, flexible in order to successfully test and repair this sophisticated equipment.

6.2 Levels of CNC Machine Service

Repair maintenance is typically identified as corrective maintenance this maintenance is usually necessary when there is an UN scheduled repair or a breakdown.

Preventative maintenance is usually planned scheduled and accounted for in traditional maintenance.

Predictive maintenance can come in many forms. It can be as simple as the traditional pragmatic machine is making noise. it can also be as sophisticated as an intelligent system with electronics and sensors to monitor multiple aspects of the machines normal operation. The major benefit of this concept is to ensure the process of conducting necessary corrective, preventative, or predictive maintenance minimizes the impact on production and downtime of the equipment.

6.3 What is Predictive Service

The concept of quantitative service quality is a fresh approach to predictive service. predictive service is unlike predictive maintenance, when you are attempting to predict what components or aspects of the machine need to be maintained . Predictive service is the process of predicting the outcome of performing that maintenance and whether or not it will be successful and meet all the customer expectations .

CHAPTER 7

DISCUSSION

7.1 Theoretical Framework

Maintenance should not be harder than it may already is. When a piece of equipment goes down, it is a stressful time. This disrupting production and can shut down regular operations. The complexity of modern equipment in use today compounds the matter even more. Getting equipment back up online gets expensive very quickly, and the last thing any manufacturer needs is to have pay for "wasted time" as the technician investigates the information necessary to make the proper repair in a quality manner.

This is an all too familiar scenario that is prevalent throughout the maintenance service industry. Many machines today are very complex or custom. Very often there is insufficient documentation necessary to assist the field technician resolve any issues. The process of locating the manual and the supporting documentation can also take up 30 to 45 minutes, at best. Considering custom machines for the many industries today and can be huge, custom, custom-built equipment with extensive manuals with thousands of printed pages. This matter can be compounded by the fact that they are printed, there's no easy way to update them. When the technician needs to service a machine at the customers facility, it is virtually impossible to be certain all the relevant technical service announcements are addressed in the documentation the technician has with them when they arrive to perform the necessary service. This documentation issue can interrupt the process very quickly with the complexity of modern sophisticated highly engineered systems. The purpose of this research and the M/R T simulation is to identify these occurrences and incorporate this a Key Predictive Attribute to assist in the prediction of quality service outcomes. As a result, when the machine technician is preparing for a service call this information is predetermined. Consequently, this is not going to interfere with the productivity of performing machine maintenance and service. Providing technicians with an easy access system linked to IIoT with the information they need. This includes real-time data a technician can access relevant to the machine's history and service data along with the service prediction and machine-specific information. A secure cloud-based system with this information can also password protected if necessary. The use of QR codes can serve as a platform to take this level of service technician informational knowledge into this new 4th Generation of 4.0 Service Maintenance. This basically allowing a technician to engage a system real time with smart technology, accessing all types of relevant information, e.g., PDFs, e-books, manuals, service updates or even videos showing step-by-step instructions on installation, clean and servicing unique components to a specific piece of equipment, make and model or even serial number. This system can even go maintenance. The system can serve as an in-house training program with key equipment-specific components. Having immediate IIoT digital access manuals and videos can help improve the process, eliminate wasted time and result in a significant reduction in system down times. All this is possible through the PQSS and QSQ system.

The possibility also exists for equipment manufacturers to incorporate this firmware solution into their equipment directly. This added functionality can ensure the manufacturer never runs the risk of missing vital documentation necessary for good quality service.

7.2 Research Questions

The first question in this study is: How can a service-oriented strategy be developed that enables manufacturing companies to provide services within the framework of services? This study defines a service-oriented strategy as "harnessing a company's ability to achieve its goals by adding service products to gain a competitive advantage". The development of service-oriented skills is one of the goals that a manufacturing company must set and achieve. In order to successfully implement the service, the service-oriented strategy therefore refers to the strategic logic of how the manufacturing company implements the service.

This problem can be solved by answering three sub-questions:

1. Which factors play a role in determining the success factors?
2. How do you determine the necessary skills for the manufacturing company?
3. Develop a plan of action, develop the skills required, and implement it.

Future research will be connected on additional aspects of this research. One category of future work will be an in-depth analysis of the reliability calculations of the results of the quantitative values generated KPA simulations. Another area of additional research will include analysis and generation of the reliability of the QSI value created by this system and/ or simulation values produced as a result of this initial research.

This system can also create quantifiable tolerances to measure and evaluate the quality performance of the service quality process. The quality outcome does not rely solely on the nominal values generated by the system. Mathematical Upper Control Limits (UCL) and Lower Control Limits (LCL) are programmatically developed based upon the system data. This system tool has developed programming algorithms which successfully propel the current process from a subjective qualitative process to become a robust quantitative projection tool..

CHAPTER 8

CONCLUSION

This research addresses the assessment of a deeper understanding of how a company and or customer develops the necessary capabilities of a service-oriented strategy, [Ulaga, Reinartz, 2011]. I've conducted my research on Computer Numerical Control (aka CNC) machine maintenance service. My focus was on one particular machine in which I studied two years of data from a HAAS CNC Lathe. I studied over 122,000 lines of operational machine code resulting in over 3,000 instances where service may be required. Further research then determined there were over 2,000 occurrences of machine interferences which required investigation and possible maintenance. Upon reviewing this piece of equipment, I then moved onto creating a process for predicting the outcome of required maintenance.

My research dissertation has created this brand-new process of product quality service. The system I've created predicts the outcome of machine maintenance service by quantifying the service through my newly created Key Predictive Attributes which I've identified as KPAs. For this program, several key predictive attributes or KPAs have been created to quantify this process. These KPAs are then mathematically calculated utilizing the created equations for each KPA to generate an exclusive composite quality index score unique to this research. Then using the Moriarty/ Ranky Transform (M/R T) algorithm which quantifies this analysis into an overall Quality Index Score for a particular expected service.

The key areas of research I focused on to create these methods are, Life Cycle service life, Risk assessment, technician experience performance factor, a unique forecasting equation, and the quantification of ten qualitative customer service factors.

The outcome of my research has culminated in the creation of a Quantifiable Service Quality system (QSQ) which simulates the use of the unique mathematical models, KPAs and the M/R T transform that validates the results of this research.

My research has created the next generation of quality service known as the 4th generation of Maintenance and Service. I have designated this method as maintenance 4.1 in the digital age of the Industrial Internet of Things (IIoT).

Service Capacity is necessary in building service process as in many ways (e.g., operations management, service business development, organization, and coordination) to accomplish an essential success factor and obtain the effective benefits. The predictive service model is a main contributor to existing resources and functions when developing this innovative format.

Service-oriented activities, ignoring the investment of additional resources and expertise will improve the long-term competitiveness of the organization, both the service supplier and the receiving customer in the market. Hence, the investigation into quantifying service as a major strategy has shown to make a significant contribution to the successful outcomes of an organization.

The contribution this research analysis supports is the formulization of a strategy to implement quantitative service prediction to ensure high quality service. By scrutinizing the importance, benefits, capabilities of this quantitative system and simultaneously enables the organization to fully or partially implement a unique methodology of future service prediction intended as a practical aid to service quality improvement and reduction of equipment service down time. This is a solid approach to CNC machine service which improves the outcome of maintenance and service significantly.

Although prior studies have addressed numerous service capabilities, they miss a detailed predictive approach for a quantified practical application of quality service as they strictly address the physical repair aspects of the necessary maintenance, and only after the fact from a cost accounting perspective do organizations address the service outcomes, [Storbacka, 2011].

While this research does contribute to filling in current research gaps, there are yet limitations to what has been concluded from this research and calls for further examination and study.

This research merely introduces a means of identifying some contributors to the approach of using KPA methods to predict and improve the service outcomes. This actually assigns the task of completion and implementation of control of this formulated service-oriented methodology to the organization.

Successful value-added service requires not only rational planning but also the concrete implementation of those plans. This fact opens further research opportunities focusing on the progress monitoring of the realization of value-added service planning.

Another limitation of this research is the requirement of a skilled and experienced analyst in strategy formulation to ensure the formulated strategies are favorable for the company. As highlighted by the board members of Company A, strategy formulation is high-level decision making. It involves intangible business instincts from the decision-makers that are shaped through long term business experiences and expertise. The proposed method provides a means to support this process. However, the skilled and experienced analysts are essential to ensure the formulated strategies are favorable for the company’s shareholders and stakeholders. Finally, this research only provided the case application in a single PSS company in Japan. Future empirical work is required to further test the service-oriented strategy formulation method in a broader group of value-added service manufacturers in a different context and industry sectors.

Capacity building is an important issue in solving this problem in many ways (e.g., operations management, service business development, organization, and coordination) and is seen as an important success factor in obtaining effective services. The service as a business contributor uses existing resources and functions and even develops new formats.

Service-oriented functions. Ignoring the investment of these resources and skills will decrease the long-term competitiveness of the market. Hence, research provides the skills necessary to examine successful service as a business employee. This research contribution in this area continues to make progress, but a deeper understanding is required to understand how to successfully transform a manufacturing company into a service-oriented business. There are still two research gaps in particular.

The First, existing research usually focuses on the general skills and process of the proposal. However, it is not yet known how a manufacturing company may determine required skills and plan appropriate development measures for its service environment. The sequence context relates to the situation (internal and external) in which the service (organizational change) takes place. It is particularly important to consider the unique service background in determining the capacity building required for effective services. The conglomeration of service products and corporate networks enables services to take many different forms. This means that the service strategy, the internal organization, and the external environment are suitable and organized.

The second research gap relates to previous research directions on the subject. Most of the existing research methods are examined through descriptive lenses (exploratory). Scientists are primarily interested in explanatory contributions and research into evidence of how things happen. At the same time, practitioners are always looking for guidance on how to implement the service. However, only a few countries have outlined the development of service capabilities. Almost no one suggests a method or model to thoroughly formulate the service strategy taking into account the service context.

While practitioners were inspired by previous descriptive studies of service-based success stories, it is important and desirable to clarify the service-based approach (particularly with a view to supporting service-oriented strategic plans) on a case-by-case basis.

The aim of this research is to fill these research gaps by proposing a service-oriented strategy development method. This method can actually help manufacturing companies analyze their service environment so that they can correctly identify the service-based functions they need and ultimately plan the development work in order to use the service successfully as business employees. This method supports manufacturing companies in particular in formulating the most suitable service-oriented strategy as strategic logic for the implementation of service-oriented strategies for the environment. The final version of the proposed method has been used in a simulation study CNC equipment. The focus of this research is the demonstration and verification of the method through the simulation created. Simulation tests confirm that this method will definitely help develop a service-oriented strategy for the company in the context of service-oriented business model.

The research contains major contributions to the quantification of service qualities body of knowledge by further defining the environmental factors of Key Predictive Attributes and quantifying these items. By analyzing these factors, the skills required can be fully determined and an action plan can be developed that best reflects the situation of the service organization. In particular, these contributions correspond to the research gap which require a deeper understanding of how manufacturing companies develop the required skills on a case-by-case basis to improve quality service. In addition to these theoretical contributions, this research provides practical support to practitioners in industry by defining the strategic logic of service-based implementation. By identifying the required skills into and developing a quantified action plans, practical methods can promote a strategic plan that can be effectively implemented throughout the organization.

APPENDIX A

EXCEL SCREEN SAMPLE

In this appendix a sample of the KPA contes is demonstrated.

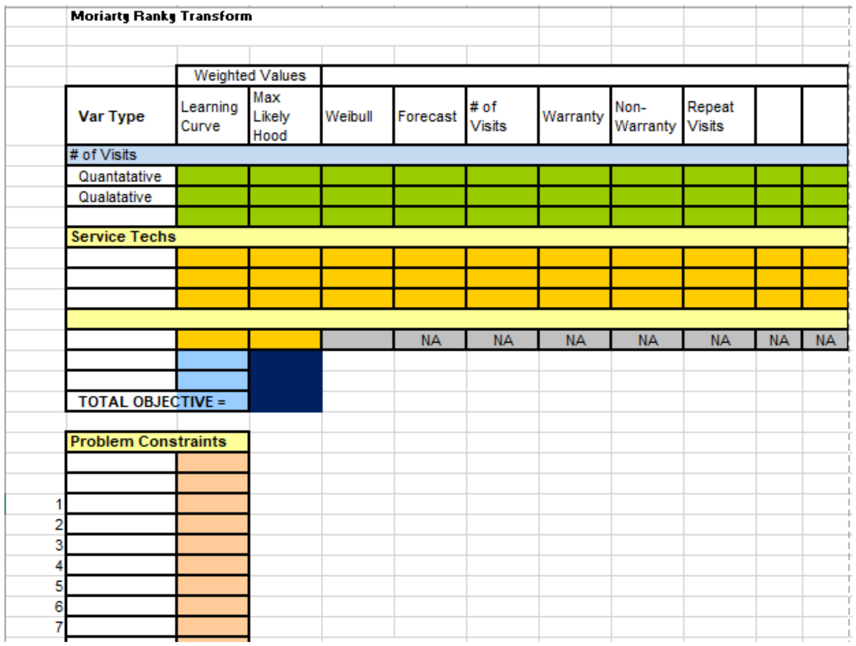


Figure A.1 Excel screen sample.

APPENDIX B

PARAMETERS OF KPA TABLES

This appendix contains the descriptions of the KPAs and displays samples of the PQSS and QSQ system as well as the created functions and the M/R T Simulation.

VALIDATION

$$\text{M/R T index \#} = \sum_{n=1}^{i} (A_i W_i) / \eta\iota, \quad (A_{ef} W_{ef} + A_{sv} W_{sv} + A_{rf} W_{rf} + \ldots + A_i W_i) / \eta i$$

A_i	INDEX VALUES	W_i		This is the description of how the simulation works with the given Key Predictive Attributes.
72.3	**Experience Factor**	99.8	$= W_{ef}$	The index value for Experience Factor indicates there is a 72.3% improvement of the service technician's time, and the Wef has a 99.8% likelihood of meeting the service time.
95.6	**Service Value**	100.0	$= W_{sv}$	The Service Value index value indicates there is a 95.6% relationship of service cost to equipment cost, and the Wsv has a 100% relationship to the over all cost of the equipment.
74.7	**Risk Function**	94.5	$= W_{rf}$	The Risk Function index value indicates there is a 74.7% relationship of service successful outcome of equipment maintenance provided. The Wrf has a 94.5% risk relationship to this maintenance and meeting the service expectations.
81.5	**Delta Sum**	100.0	$= W_{ds}$	The index value for Delta Sum indicates there is a 81.5% likelyhood of being accurate with the data provided and the Wds has a 100% relationship of this forecast to this service.
97.5	**Service Life**	100.0	$= W_{sl}$	The Service Life index value indicates there is a 97.5% relationship of product service life cycle to this service. The Wsl has a 100% likelihood of being significate to the outcome.
78.6	**Qualitative KPA's**	99.0	$= W_q$	The Qualitative KPA's index value indicates there is a 78.6% relationship of the ten qualitative attributes identified and quantified for this function, the technician and the equipment. The Wq has a 99% quantitative value with regard to the qualitative relationship to this maintenance and meeting the customer service expectations.
90.9	**Most Likely Outcome**	85.7	$= W_{ml}$	The Most Likely Outcome index value indicates there is a 90.9% relationship of service life cycle to this service. The Wml has a 85.7% likelihood of being significate to the outcome.

99 = η **newly created normalizing factor**

Figure B.1 M/R T Simulation description analysis for the purpose of validating the analytical methods.

M/R T Simulation,

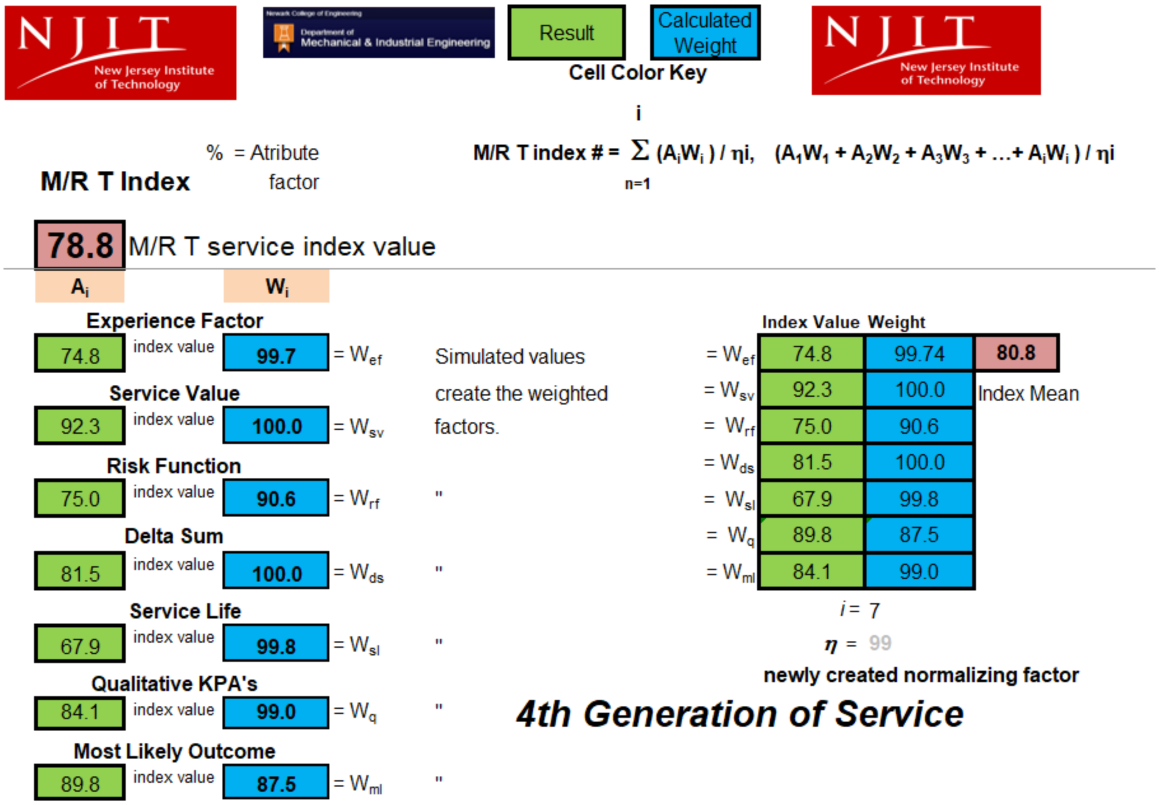


Figure B.2 M/R T Simulation main index page.

KPA List and Equations,

- Experience Factor

$$\Psi_{\Gamma} = (\alpha\Gamma^{\beta})\ \eta$$

- Service Value

$$SV = \eta - (\eta\ [C\,(1+i)^{t}\ /\ P\,]\ /\ \upsilon)$$

- Risk

$$\text{Graded likely Risk function} = (1- X_{sim})\ \eta$$

- Delta Sum

$$F_{\Delta\Sigma} = (1-\lambda)(\text{Last Service}) + 0.5\,\Delta + \lambda(\text{Last Estimate})\ \eta$$

- Service Life

$$F(sl) = [1 - \exp(\ (sl-\alpha)\ /\ \beta)]\ \eta$$

- Qualitative KPAs

$$KPA_{q} = (M_{x}V - \bar{X}_{sim})\ /\ \bar{X}_{sim}\ \eta$$

- Most Likely

$$\text{Simulation Mean } \bar{X}$$

Figure B.3 KPA index equations.

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