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Development of new models for measuring hardware and software quality in GSM Radio Base Stations

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Abstract

Development of new models for measuring hardware and software quality in GSM Radio Base Stations

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This thesis involves the development of new models for measuring quality in software and hardware which is used in Ericsson's Radio Base Stations. The time consuming work of finding the sometimes small and troublesome areas within a large population is currently being done manually with some assistance of a modified version of Mean Time Between Failures (MTBF). The old calculation and presentation format is limited and needs to be upgraded. This is where the author's contributions, Argus and the Watchdog (A&W), enter the scene. Argus is a model that uses quality points per fault code to summarize the impact from each fault code on a revisions quality. The Watchdog focuses on the individual fault codes and uses a filtering function and equations to find the fault codes that are indications of deteriorated quality. The problem that the author's models are facing is to pinpoint and present the major contributors to poor quality among Ericsson's Radio Base Stations. The author's models will be presented in the light of existing quality models and theories, to determine how other models would have solved the problem with finding the vital information within a huge population and presenting it in an apprehensible way. If the other models and theories are not applicable, then the authors will extract the positive bits and use them for inspiration. Argus and the watchdog will evaluate a number of revisions, with fault codes, which has already been analyzed by experts, to determine the validity of the author's models.

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Sammanfattning

Kvalitet har sedan den industriella revolutionen allt mer blivit en het potatis. Företag har insett att det går att tjäna stor summor pengar på att hålla en hög och jämn kvalité jämfört med sina konkurrenter. Ericsson har under senare år fokuserat på att bibehålla sin generellt sett höga kvalité för att kunna ta ut ett relativt sett högt pris. Om kunderna känner att de får valuta för de pengar de investerar i Ericssons radiobasstationer kommer de att fortsätta att utveckla samarbetet med företaget även i framtiden. Kvalité är därför ett område som kräver kontinuerlig utveckling och det är mot denna bakgrund som denna examensuppsats träder in. Arbetet syftar till att skapa ett par nya modeller för att mäta kvalité i mjuk- och hårdvara. Modellerna utvecklades med en inkrementell och iterativ ansats. En inkrementell ansats syftar till att dela upp problemet i mindre och hanterbara enheter. Vid en iterativ utveckling går man tillbaka till tidigare lösningar via tester och utvärderingar, detta för att säkerställa att den planerade och utförda lösningen är den bästa.

Under arbetets gång skapades två nya modeller: Argus och Watchdog. Argus utför analyser på en högre nivå och utvärderar till exempel revisioner och kabinett. Med hjälp en viktfunktion i Argus, som av oss kallas QPI, paras varje felkod ihop med ett kvalitetsvärde. Ett högt värde är en indikation på att en felkod bidrar negativt till den sammanlagda kvalitén. Quality Point Index (QPI) värdet sätts av en kunnig analytiker och kommer att behöva justeras i framtiden för att kunna avspegla den rådande situationen. Alla felkoders kvalitetsvärden, i en hel revision, summeras sedan ihop av Argus och de revisioner med högst totalsumma kommer att presenteras i en tabell och med hjälp av lättförståliga grafer. Watchdog är skapad för att reagera på negativa förändringar på felkodsnivå. Varje felkod jämförs antingen med ett fördefinierat högsta värde eller med ett medelvärde. Om differensen är positiv kommer dessa felkoder att sorteras så att analytikern kan fokusera på de felkoder som uppvisar störst tecken på att kunna bidra negativt till kvalitén. För att kunna undvika att finna stora differenser hos de felkoder som analytikern för tillfället anser vara oviktiga, har det i Watchdog lagts till en filterfunktion. Dess parametrar, vilka de ska släppa igenom, sätts av analytikern själv.

Våra modeller kommer att jämföras med liknande kvalitetsmodeller, för att undersöka hur andra modeller skulle ha löst problemet. Life Cycle Cost Analysis och Six Sigma ter sig mer som metodologier och har därför fungerat mest som källor för inspiration. Statistical Process Controll och Mean Time Between Alarms kommer att vara de modeller som vi jämför våra modeller med samt utvärderar hur dessa hade angripit problemområdet. För att säkerställa våra modellers validitet kommer vi att genomföra en analys med våra modeller, där indata redan har analyserats manuellt med en rapport utförd med hjälp av MTBA, där svaret redan är känt.

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1. Introduction

Quality is a way to attract and keep customers. The concept of quality in our time is embracing every aspect of the company and the business idea.[1] A successful business with lots of income-brining customers is almost always associated with good quality.[2] Income could be seen as the fuel of the world, but also the object of desire for persons, families, cities and countries. The things that are good for a global company can be beneficial both on individual level and also on geographical level. This is why it is useful to investigate things that are of greatest importance for corporations. Quality is increasingly becoming a more vital aspect for companies trying to maximize its profits.[3] In the beginning of the industrial revolution the goal was to manufacture as many goods as possible. The lowering of trade obstacle during the last decades has increased the global competition for customers.[4] The trend towards increased competition means that companies have to try to stand out from the ever growing crowd. Typically companies either lower their costs or try to be in the premium sector [5] with higher quality than the major part. Increased quality is often connected to increased costs but it can also lower your costs, since fewer products has to be repaired and more focus can instead be placed on producing more and better products. Better quality often leads to more orders and that can lower the production costs per part and thereby save money.[6] A penny that is saved can be turned in to a profit and profits are what govern the world. Quality can be good for a company, both since it can lower costs but also because it can move the company to the premium sector. Being in the premium sector and at the same time spend less money on faulty products than your competitors means more money for the stockholders. Ericsson can be said to be in the premium sector, with a big market share, and is constantly trying to improve the quality of the products and at the same time lower their costs. Quality is and will always be a vital part of companies in general and also at telecom companies like Ericsson. This is why the authors thought it would be a good idea to look closer at quality at Ericsson.

Models, such as Mean Time between Alarms (MTBA) and Mean Time Between Failures (MTBF) [7], can be used to predict the future from a failure point-of-view and a company who can act preemptive stands to earn a lot of money. Companies hope to increase quality by finding a suitable substitute for the manual models, since a model that automatically would analyze the quality on different products within a company would save time and money. Employees that normally would do the manual part of the analysis can focus their attention on other parts that can't be done by a computer model. An automatic computer generated model would as stated save time, but also analyze more material then any human ever could. This minimizes the possibility that vital parts are overlooked. Both the time aspects and the volume aspects are good reasons why an automatic model would be important investigate further.

Statistical Process Control (SPC) [8] is quality measurement tool that has reshaped the economic map. Its profound impact [9], on both production and how companies are run, makes it unique. It has been used by companies since the 1930s and Ericsson a caught the SPC-wave in the mid 1980s. Since then it has been used to secure Eriksson's place among the top companies in Scandinavia. Other influential quality models are Six Sigma [10] and Life Cycle Costs Analysis (LCCA)[11].

A brief history of quality:

- Pre-industrial revolution: Craftsmen controlled the quality through their common pride of workmanship.
- 1880s: Quality was controlled through tools developed from Fredrik Taylor's "Scientific management"
- 1920s: The process of manufacturing was influenced by Shewhart's theories regarding continues quality monitoring by the operator (SPC).
- 1930s: Dodge and Romig began using probabilistic approach to predict quality based on sampling results
- 1950s: W.E. Deming introduces statistical process control to Japanese industries.
- 1980s: "Quality revolution" starts in Northern America when Ford hires Deming as consultant.
- 1984: U.S. Government designates October as national quality month
- 1987: Malcolm Baldridge national quality award is established
- 1990's: Quality programs are spread to service industries. Programs like Total Quality Management, Six sigma, Kaizen, Poke Yoke, Taguchi Methods, Benchmarking, CQI and FMEA becomes trendy.[12]

Ericsson annual worldwide sales of Radio Base Stations are a significant part of Sweden's BNP. They billed their customers for a total of 177,7 billion SEK and had a total profit of 35,8 billion SEK during 2006.[13] Ericsson is therefore a good and suitable place to conduct research regarding models that automatically measure quality.

1.1 Reason for improving quality

Quality is essentially about learning what you are good at and learn how to do it even better. It also means finding out what you may need to change to make sure you meet the needs of your customers. Quality is about:

- knowing what you want to do and achieve it
- learning from your mistakes
- using what you learn to develop your organization and its services
- seeking to achieve continuous improvement
- foresee unanticipated events and future needs
- and by all this satisfy the shareholders/stakeholders

Reasons for choosing high quality can be numerous. Everything from ethics, environmental and culture can be said to influence the degree of quality. High quality in every part of the process means a higher possibility of doing it right in the first place, thus minimizing the chance for having to do the same work several times. Correcting a fault within the company before the product reaches the market is much cheaper than correcting it after it has arrived to the customer. The authors will in this thesis, similar to the scientific reports on SPC, focus on the economic side of quality.[14]

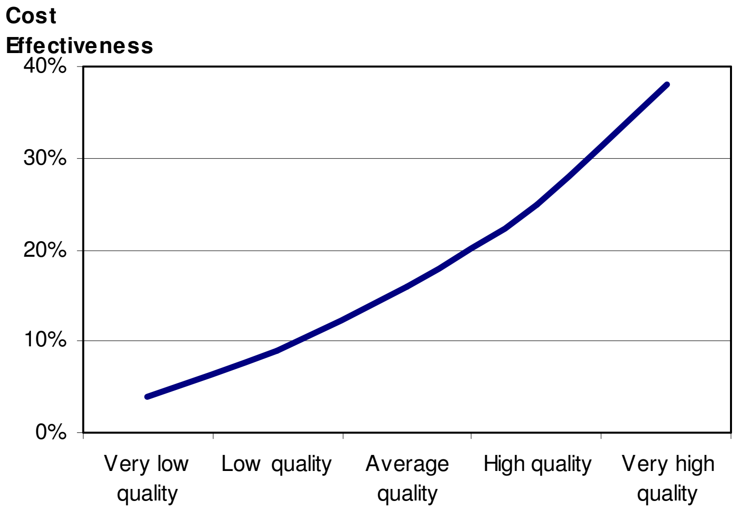


Figure 1 - Return on working capital in correlation with a company's quality reputation[15]

A good reputation, se figure 1, can be obtained if a company produces products with a high reliability during a long period of time.

1.1.1 GSM Radio Base Stations and quality

Ericsson's GSM System is a mobile system containing the frequencies 800, 900, 1800 and 1900. A GSM network can be divided into three systems called Switching System (SS), Base Station Systems (BSS) and Operation and Support System (OSS). The switching System is the top system based on AXE technology and performs switching functions, registration functions, authentication, identity register etc. The Base Station System consists of Transcoder Controller/ Base Station Controller (TRC/BSC) and Radio Base Stations (RBS). The Base Station Controller manages all radio-related functions, including calls, over a GSM network. The BSC functions as the master and controls its underlings; the RBS: s. The Radio Base Station handles the radio interface to the mobile phone. The cabinet (The RBS) contains all radio and transmission interface equipment needed to sustain a telephone call using a mobile phone. GSM communication structure: MSC/TRC ←→ BSC ←→ RBS ←→ Mobile phone.[16]

Low total life cycle costs and long MTBF has been achieved in the newest generation of RBS: s, namely the Ericsson's RBS 2000 product family. Even though they are new and made with the greatest of care, they still suffer from sporadic flaws in quality. A RBS unit that has high quality is one that functions without being noticed. If everything works as predicted then nobody except Ericsson and the operator will ever know it even exist. Poor quality can take the shape of dropped calls, missed handovers (between different RBS: s) and a complete loss of traffic. The search for flaws regarding quality, in cabinets installed by Ericsson, is currently being done manually by people working at Operations & Maintenance (O&M). They are forced to look at numerous paper-reports and retrieve the vital parts by comparing one revision with a couple of others. The number of reports that needs examination can be several thousands. Monthly statistical reports using MTBA have been handed over to senior management at Ericsson. [17]

1.1.2 Definition of poor quality

The definition that is being used when performing the manual analysis is: "Poor quality exists in a revision when the numbers of alarms, that are above the maximum limit, are above a certain level." This is a subjective value since the certain level depends on the type of revision and the analyzers experience. This simplistic definition is somewhat flawed but sufficient during the manual analysis. The problems with the old definition are that few RBS:s can offset the entire quality calculation if they are responsible for a big portion of the alarms and alarms can not be weighted against each other. The authors decided to use another definition to determine if a Transceiver Group (TG) has bad quality. The definition states that: "Poor quality exists when the amount of alarming TGs is above a maximum limit." The advantages with this definition are that the analyzer can detect when many TGs have small problems and alarms can get different priority. This definition would serve both a high level analysis and low level analysis. By high level analysis the authors mean an analysis on revision level (i.e. software/hardware level) and low level analysis refers to an analysis on fault code level (the alarms that is send from cabinets). A new revision is an alteration of existing software or hardware and it would be beneficial to determine, for example, if revision number 7 is better than revision number 6.

1.2 Problem formulation and purpose

To be able to find the items that negatively affect quality the authors will have to find the vital data within a huge population. The problem of finding the essential information can be described as finding a needle in a haystack. This tedious work has been done manually in the past with some assistance of Mean Time Between Alarms (MTBA).

When the essential information has been located among thousands of reports, the problem of presenting the information arises. The reports has to be manipulated to show only the most important information in such a way that the analyzer doesn't get confused or overwhelmed[18] by the sheer volume of data.

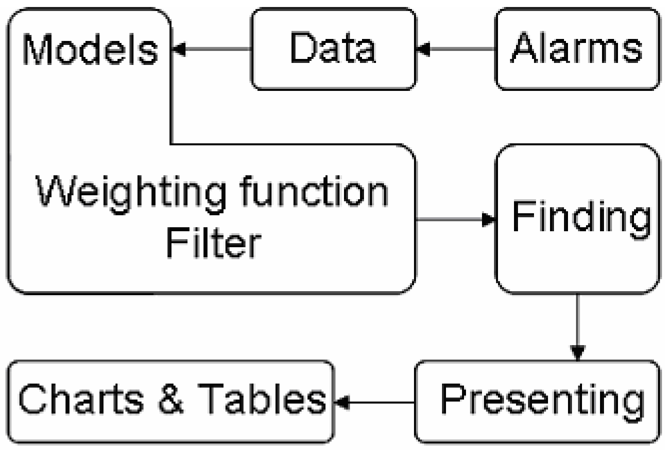


Figure 2 - Flow chart of each step in the analysis

How different items are connected to each other in and around the authors models can be seen in figure 2. The purpose with the model is to pinpoint the fault codes and the revisions that are the major contributors to poor quality. The models are supposed to assist the analyzers by performing the sometimes tedious work of going through lots of paper reports and lead the analyzer in the correct direction. The exact quality value is of less importance. The output from the models shall be used as feedback to Ericsson's design organization, forming base for prioritizing actions aiming to improve quality.

The findings will be discussed in the light of an existing manual procedure with MTBA and other methods used in quality controlling, such as SPC, LCCA and Six Sigma. The authors intend to see how the other models would have dealt with the problem.

1.3 Limitations

The model can only detect what the analyzer should focus their attention on and can not find the root cause behind the values or behind the negative trend. An analyzer currently uses his entire knowledgebase to find the root causes behind alarming TGs and the number of possible causes is astronomical. Finding root causes is certainly an important and interesting part, but it is out of the scope of the thesis.

The input to the models comes from RBS In Service Performance (ISP) Tool and the amount and type of data from that tool sets limitations on what the created models can do. The research is supposed to be used as templates when Ericsson Operation & Maintenance (O&M) wants to include new functions within RBS ISP Tool. This means that the models and its code will not be used without heavy modifications. Less effort has been put in making a complete model that will work under all circumstances and instead focused on making a model that will be good enough for a weekly meeting when the revisions are analyzed.

All data in the examples, tables and figures which uses information from Ericsson is fictive. This has been done because the data has been classified as sensitive. This precaution doesn't change the models or the thesis report; it merely changes the output which should be used as input for further analysis. When O&M department uses the models, they will use correct data and the output can therefore be directly used as base for a deeper root cause analysis.

The RBS ISP Tool delivers significant information but its full potential is not fully realized with the Argus and Watchdog (A&W) models. The validity could further be increased if the models would be adapted to take into account data regarding down-time. This data is recorded within RBS ISP Tool and currently being used when the employees performs their manual analysis. The authors have modified the models to suit the input data and its structure, but has not used down time since it lays outside the scope of this thesis. They believe that data that are being used is sufficient in order to draw conclusions regarding quality deficiencies.

1.4 Outline of the thesis contributions

The thesis and its contributions to measure HW and SW quality are presented in depth in chapter 6. Only the major contributions will be outlined in this section. A more detailed discussion together with the models way of dealing with the problem formulation and purpose is included in each section that deals with the problem. The main contributions of the thesis report are:

- A couple of quality models which are relevant to the author's models are identified. The advantages and disadvantages of these models will be introduced and a comparison between some of them and the created models will be given.

- The benefits and functionality of Argus and Watchdog are stated.
- The models can pinpoint the major contributors to a decrease in quality in a specific hardware (HW) / software (SW) revision.
- Argus and Watchdog can be adjusted to put different weight on certain fault codes and they do their calculations on the number of alarming TGs.
- Comments on how to improve the RBS ISP Tool function have been included.
- All coding with explanations will be used as templates for future development and research.

1.5 Target audience

This rapport is supposed to be read by people who work at Ericsson, people who study Sociotechnical Engineering at Uppsala University and those who study to become an Electronics Engineer at Gävle University. People who have a general interest in quality models can also benefit from reading this report.

2. Method for developing the models

The developers of the A&W models used the incremental and iterative approach, with stepwise upgrades and implementing what was has been learned during the process. Iterative and incremental development[19] is a common way of developing software and learning comes from both the development and use of the system. Key steps in the process were to start with a simple implementation of a subset of the software requirements and iteratively enhance each revision until the models are finalized. Design modifications and new functions were added at each iteration.[20] When applied and used to the fullest extent the development model can be presented as it has been done in figure 3.

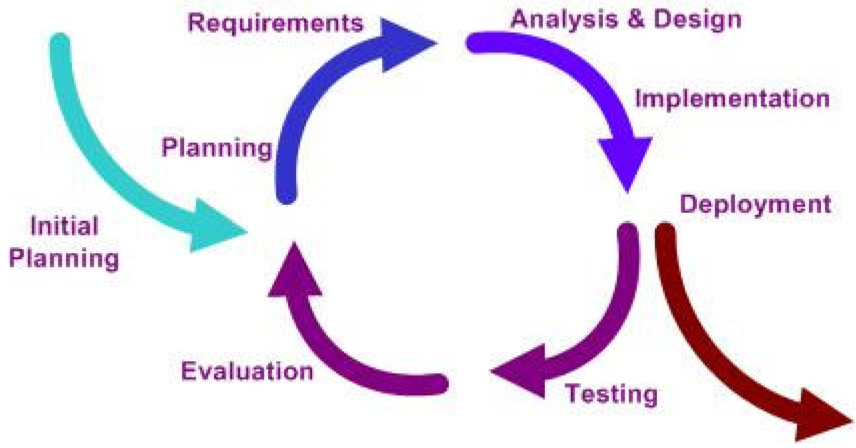


Figure 3 - Iterative and incremental development

This way of using iterative approach increased the validity since the developers could analyze the reports which the models created and make a new iteration if the results weren't good enough. If one of the new parts didn't work as planned or caused serious damage to the rest of the model, the developers could simply go back to a former version and continue to work from a revision that they knew worked. As the models grew in size, they also grew in complexity. It became harder and harder to foresee how a new part would influence the rest of model. The developers had to, from time to time, go back to a previous version and rethink the implementing approach.[21] The developers never abandoned an idea, they just went back one version in time when they encountered a serious implementing problem. When the authors started again with a former working version, they could find a new way of implementing the wanted function without causing serious damage. The notion of never discarding an idea came from the understanding that other developers must have encountered similar problems before.

"Even the best code writers like to start with an example, because
They're lazy.
It's easier."
Microsoft Webpage Office Excel Training[22]

3. Input data

The authors will in this section describe the different input data that will be used by the models. They have placed this information before the related work so that an analysis of the other models appropriateness in relation with the input data can be done.

3.1 Input from GSM RBS ISP (In Service Performance) Tool

Ericsson receives data from 10% of the installed base and has decided that this limit is sufficient and they can’t currently handle more information. They have a hard time processing all current data so they wouldn’t be able to handle more data even if they had access to it.[23] Argus and Watchdog (A&W) could help Ericsson with this problem since the models can handle larger amount of data than humans ever could. This would mean that Ericsson could possibly increase the number of units with RBS ISP Tool, if they felt that they by this action would get a more accurate view of the current situation. Another advantage with A&W is that they do the time consuming work that is currently being done by regular employees at Ericsson. If Ericsson used A&W, their analyzers could then focus their attention on analyzing the items that A&W pinpoints as extra important for further investigation. This would same time and enable them to focus more on finding the root causes behind the poor quality instead of focusing on finding the single most important digit in hundreds of papers.

GSM RBS ISP Tool is a function in the operators OSS (Operators Support System) which gives Ericsson valuable information about RBS performance. For the operator, the purpose is to find possible problem areas (RBS, transmission, power, antenna installation, etc.) and monitor the performance of their GSM Radio network and maintenance organization.
The purpose for Ericsson is to monitor the performance of the RBS 2000 HW and SW, disturbances on the transmission and internal power. It is Ericsson who provides the operator with the collected data via monthly reports. The data is also used to identify the magnitude of problems and to find root causes. The magnitude of the problem is described in reports like number of alarms, duration of alarms, TRX/Cell/TG Downtime as output. It can also give high level statistics on network level or detailed statistics down to Replaceable Unit (RU) level. Ericsson uses the information to improve its products and to find problems before they can severely affect its products and cause harm to the operators.[24]

The tool is free of charge and all operators are currently welcome to apply for it.[26] The operator must approve the use of this application before configuration and activation. If they approve, then the GSM RBS ISP Tool collects GSM RBS alarm data from the new RBS 2000 products. Currently there are more the than 20 operators who have installed this tool and who thereby share important information with Ericsson. The collected data is automatically sent to Ericsson by mail and stored in a database.[27] An analyzer can retrieve the information via a web interface and demand that a specific part of the large database will be emailed to his email address. The reports from RBS ISP Tool contain information about different Operators, SW-revisions, HW-revisions, Cabinets or OSS: s. Cabinets are the different types of RBS: s that Ericsson manufactures. An example of such a cabinet could be the new RBS 2216 which is an indoor cabinet that can handle more traffic than its predecessors.[23]

Three different types of files will be used in the created models and they are called base data file, result file and input file. Base data file and result files are outputs directly from RBS ISP Tool and will form the input to the models. These files will be converted into input files by A&W so they might be able to extract and manipulate the information within them. Fault codes that are above a maximum limit will be extracted for further analysis from the input files. The maximum limit has been set by the employees at Ericsson and functions as an upper limit that shouldn't be broken if all is well. There is also an average limit and it is calculated and set by the RBS ISP Tool. That number can be seen as an early warning sign or a reference point and if the number of TGs exceeds the average limit and that could be interpreted as a need for further analysis. We have chosen to only deal with fault codes that are above the maximum limit, since it decreases the number of fault codes per revision that are interesting but also because they are clearly beyond the level that has been stated as the line between good and poor quality.

The data comes from 10 % of the installed base and that number has Ericsson determined to be sufficient. They have tried to place the tool within diverse geographical regions with different weather conditions. Another criterion for the dispersal has been to place them within regions of dissimilar traffic patterns. All this has been done to ensure that the data being stored in the database gives a good representation of the overall scene. Another reason for not collecting more than 10 % is that Ericsson can not handle more information at the moment. They are currently not analyzing all available data, so gathering of more data would with current resources be futile.[25]

Presenting information in a good way, according to Blom & Holmquist, that enables easy access to the most vital parts is a form of art. It is essential to compress the information to ensure that the analyzer doesn't get confused by the sheer amount of information.[26] Two important factors, when performing a sampling in order to create a model, are: the need for randomness and the need for removal of disturbing factors. All normal statistical theory is based on the assumption that the data is randomly sampled. A sample doesn't have to be an exact miniature replica of the population if the sampling is done randomly. It is often a good thing if a replica can be made but it is never a required attribute of a statistical survey. It is necessary to understand that total randomness is often impossible to achieve in the industry. Blom & Holmquist doesn't give an exact recipe of how an analysis should be conducted when complete randomness is absent, they only state that extensive background knowledge is required before such a survey and analysis is conducted. The analyzer should always try to remove disturbing factors. Examples of such factors can be systematical errors, i.e. uncalibrated machinery, and reduction of elements i.e. only certain elements are covered in the survey. In an ideal situation, no disturbing factors are present. This ideal situation should always be the goal, but it is almost impossible to accomplish this outside a laboratory.[27]

The rule of thumb for the size of the sample is that it should be "big enough". The more you know about a population, the better your calculations and predictions will be. A recurring number, used on random samples, set by Blom & Homquist is a sample size of: $n \geq 10\%$. The relative number is of less importance since the population is huge. The error decreases proportional to the sample size and that should lead to a small error in the data from the RBS ISP Tool.[28]

3.2 Quality index (QPI)

To the author's knowledge, nobody has tried to attach costs or quality points to an individual fault code from the RBS ISP Tool before. This way of examine quality might be unique and its potential is vast if the quality values are appropriate. Different fault codes affect its surrounding actors in different ways. A customer could for example be severely affected if his external power source to his RBS shuts down. The same problem is of no concern for Ericsson since it is not their responsibility. The author's way of dealing with this predicament is to create a weighting function called Quality Point Index (QPI). Costs will be used as synonym for poor quality since this two is often strongly connected to each other.

The QPI is essentially the heart of Argus. If the QPI data is incorrect the entire analysis will be misleading. The values in QPI don't have to be exactly correct but at least in the vicinity of the correct value. If the analyzer is aware of this fact, he would then still be able to draw some conclusions on what revision to focus on. The final values in this QPI will be based on the entire knowledge in the O&M department and they must be adjusted and fine tuned until they are good enough.

The general idea is to attach a value to each fault code for a specific category. The value is then multiplied for each fault code and summarized within each revision. These values are calculated by Argus and sorted to show the revision with highest total value. Categories in this index are currently Ericsson, Operator and Subjective costs. The model can function with more categories if that is required. Examples of future categories could be SW, HW and external factors.

Three categories of QPI exists at the moment.

1) The Operator QPI is calculated by adding the following cost or quality elements

- Dropped calls.
- Missed handovers.
- Site visits.

2) The Ericsson QPI is calculated by adding the following cost or quality elements

- Repair.
- Claims.
- HW.

3) The Subjective QPI is an estimate of the magnitude of the annoyance created by a fault code (e.g. Reset SW fault)

The 3 categories are a massive simplification of the RBS-scene. The authors have tried to keep it simple and start with as few categories as possible. The category Operator could for example be divided into smaller sub categories like dropped calls and missed handovers. Reasons for a high score in QPI under the operator category are currently a weighted combination of the sub categories explained the former sentence. The number of potential subcategories is only limited by the analyzers imagination. Operators act in unique environments and the goal is to find the number of sub categories that is manageable but at the same time gives a "good enough" description of the situation. The category Ericsson deals with items such as replaced hardware during the warranty period. All things that directly influence Ericsson in negative way are placed within this category. Subjective costs are those things that are annoying for Ericsson like TRXC I1A:4 Reset SW Fault. Annoying refers to things that i.e. take a long time to amend.

3.3 Sensitivity of the input data

The input data in the models is not randomly picked but it can be said to represent a miniature replica of the population which increases the reliability and validity. The employees at Ericsson, who decides which operators should have RBS ISP Tool, can be said to have extensive knowledge of the overall situation. This should to some extent compensate for the lack of randomness in data gathering part RBS ISP Tool.

The calibration of the apparatus that reports RBS-alarms is essential but nothing that the authors can affect or investigate. The authors can only hope and assume that this is being done with the highest possible accuracy. The reduction of elements has been considered by Ericsson and their way of spreading RBS ISP Tool among different operator is one of way to tackle this problem. This is no ideal solution but it is at least an attempt to circumvent this problem.

10% is, according to Blom & Holmquist, the lower limit on the sample size if the analyzer wants to be able to draw any conclusions regarding the rest of the population. This percentage number is calculated on a random sample and the author's book is unclear on what needs to be done if the sample isn't random. Ericsson is aware of the situation and since they can not process more data at the moment then 10% must be said to be "big enough" and "good enough". It would certainly not hurt the analyzing part if they received data from more than 10%, if they were able to process it.

One of the results from the authors way of using the data from RBS ISP Tool is that it has become apparent that 1 decimal isn't enough in the input data. An increase from 0,1 to 0,2 is massive increase in percentage. The separation among these fault codes, when performing calculations, would be simplified if there where more decimals. Some of the fault codes exhibit step wise behaviour, with increases in multiples of 100% due to the low number of decimals.

4. Related work

Researchers have during a long time been interested models for measuring quality. Their research has resulted in models such as MTBA, LCCA, Six Sigma and SPC. These models will be presented in the following chapter.

4.1 Mean Time Between Alarms (MTBA)

During the weekly meetings a couple of analyzers sit down and manually analyze a small amount (less than 10) of revisions or operators. SW or HW revisions that are chosen for these meetings are often new or they might have had complaints. The analyzers look for an increase or decrease in the %-values and focus on the alarms that are reported to be over the maximum limit. When they have found the fault codes responsible for change in quality, they start looking for common factors. The search for common factors is a part of the search for the root causes and this search is the final step in the manual model. Once every month, the analyzers compose a report for the senior management with the assistance of MTBA. This model is used to create single value to determine the overall quality.[23] The drawbacks of this model are that all alarms are treated equally and that the analyzers have to count the number of alarms instead of TGs that are affected.

4.1.1 Reasons for using MTBA

Mean Time Between Alarms is measurement tool that has been developed by Ericsson which is measured for response for SW release. It is similar to Mean Time Between Failures (MTBF) and Mean Time Between Accidents. In the following discussion, MTBF will be replaced by Ericsson's MTBA. For measuring HW and SW quality, a reliability model is typically used to describe the component or system's reliability[29], where reliability is the ability of a system or component to function properly under certain conditions for a pre-defined period of time. It has been developed to predict the performance compared to design targets and a company requirements.[30] The relation between MTBF and reliability is according to equation 1:

$$\text{Reliability} = e^{-\left(\frac{TIME}{MTBF}\right)}. \qquad (1)$$

As can be seen, higher MTBF means higher reliability of a component or product.[30]

4.1.2 Basic features of MTBA method

MTBA is the mean time between alarms of the whole system. The equation (2) for calculating the MTBA is:

$$\theta = \frac{T}{R} \qquad (2)$$

θ = MTBA
T = total time
R = number of failures [32]

Sometimes failure rates are measured in percent failed per million hours of operation instead of MTBA. Failure rate is denoted by λ (lambda) and it is the frequency by which a component or system fails to function properly. The failure rate has the following relationship (3) with MTBA:

$$\text{MTBA}=\frac{1}{\lambda}. \qquad (3)$$

As can be seen from this equation, a larger value of MTBA and a low value of failure rate can be found in a high quality component or system.[31]

The purpose for the customer is that the BTS availability (down time) and Traffic affecting alarms shall be at a reasonable level. For Ericsson, the purpose is to maintain operational excellence, i.e. the same high SW and HW quality.

4.1.3 The MTBA model

The data source to the MTBA model is RBS ISP Tool, which collecting alarm information from customer's GSM-networks. Alarms caused by external factors, like Mains Failure and Reset Switch are excluded from the calculations. Only relevant Class 1 alarms form base for calculations. The Mean Time Between Alarms is the inverse of the Fault Intensities (FI).The FI (4) is the number of alarms weighed towards the number of equipment and elapsed time that has generated the alarms:

$$FI = \frac{N_{cl1}}{N_{eq} * t} \qquad (4)$$

N_{cl1} = Number of Class 1 alarms

N_{eq} = Number of equipment [17]

The alarms associated with DXU (Distribution Switch Unit) SO CF contribute to FI DXU.
The alarms associated with TRU (SO TRXC, TX, RX,) contributes to FI Transceiver and Receiver Unit (TRU).
The FI_{RBS} (5) and MTBA (6) is for a "Model RBS" consisting of 1 DXU and 6 TRU:s.

$$FI_{RBS} = FI_{DXU} + 6FI_{TRU} \qquad (5)$$

$$MTBA_{cl1} = \frac{1}{FI_{RBS}} \quad [17] \qquad (6)$$

The advantages of the MTBA model are:
Advantages:

- The reliability can be calculated from the MTBA value.
- It can detect the current and historical situation.

The disadvantages of the MTBA model are:

- The analysis only focuses on an average of the population, it is therefore hard to find problems that occur in small parts of the population and these problems might get overlooked.
- The analysis only chooses relevant Class 1 alarms as a base for calculations. All

alarms have the same influence over the MTBA value.
- Different revisions have different numbers of TGs. MTBA only looks at an average level, and therefore it is not accurate in some of the diverging parts.
- The result obtained form MTBA is due to manual work. This procedure, even with only 6 revisions, will require a lot of time so it is fair to say that the job can be considered to be tedious and time consuming.
- Bar chart will be chosen to present the result of MTBA for each revision. All revisions will be placed in the same chart so it becomes crowed and it is hard to detect trends, shifts and small differences.

4.1.4 Could MTBA be used to solve the problem?

The model has been used in the O&M department at Ericsson to find problematic areas in the past. The model has been determined by the authors to be less than perfect and they feel that the department is in need of a model that can replace the MTBA. The drawbacks with MTBA are mainly:

- All relevant alarms are treated equally and no weighting among them can be performed. Unimportant alarms can therefore influence the analysis and it becomes misleading.
- The model uses the old definition of poor quality, which counts the number of alarms that are above a maximum limit. It is of less importance to find a single RBS that are responsible for a big portion of the alarms and the MTBA often focuses on such RBS:s.
- It is hard to find problems, when using MTBA on data from the RBS ISP Tool, that occur in small parts of the population if you only look at an average of the entire population, which you do with the MTBA model.
- The MTBA model lacks flexibility.
- It presentation format is limited to one chart.

4.2 Life Cycle Cost Analysis (LCCA)

4.2.1 The definition of Life Cycle Cost

The national institute of standards and technology (NIST) Handbook (page 135, 1995 edition) defines Life Cycle Cost (LCC) as “the total discounted dollar cost of owing, operating, maintaining, and disposing of a building or a building system” through its full life cycle.

The total cost of a product through its life cycle contains “acquisition cost” and ownership cost like operation cost, maintenance cost and many other cost categories. The life cycle cost analysis (LCCA) is an economic analysis technique that determines the over-all-long-term cost of owing, operating and disposing of a product or service. It provides methodology for calculating a forecast of the cost of the product or service over its entire life. In a typical electronics company, the types of costs are design, production, repair, travel, warranty, SW upgrades, labour cost etc. It attempts to find the best ways for project management to lower cost expenditures.[32] The typical system or product may include costs in following aspects:

- Planning
- Research and development
- Production

- Operation
- Maintenance
- Cost of replacement
- Disposal or salvage

The timetable of life cycle costs has an important role in scheduling cost. It helps to show which costs need to be arranged to a proper product so that the organization can recover its costs. However, if all costs can not be recovered, the product or service might be cancelled. The life cycle cost analysis is very vital for the cost accounting. It enhances the importance of locked-in cost, such as research and development (R&D).[33] The life cycle cost analysis has three major benefits:

1) All costs which are connected to the product/project become visible.
2) The analysis of business function shows interrelationships within the company. For example low repair costs could then lead to a strengthen position for the entire company.
3) The different costs in the early period are highlighted to accurately predict the future income.

LCC analysis can be applied for:

1) Long term financial planning
2) Cost identification for cost effective improvements
3) Evaluation and comparison of alternative designs
4) Evaluation of the economic viability of products
5) Assessment of product warranty through verification tests [34]

4.2.2 The purpose of using LCC

LCC helps change the overall estimation of the financial burden by enhancing business competitiveness through a search for the lowest long term cost of ownership. Different aspect will focus on different parts of the economic problem:

- For project engineering: minimizing the primary cost is the only criteria
- For production: maximizing the uptime hours is the only focus
- For maintenance engineering: minimizing repair hours is the only criteria
- For reliability engineering, to avoid failures is the main goal
- Shareholders are almost always only focused on obtaining the maximum wealth.[35]

4.2.3 Basic process of LCC analysis

There are some fundamental differences between LCCA and A&W, but common and essential step can be found. The LCCA process can be summarized as seven basic steps as follows: [36],[37], [38]

<u>Process1: The problem definition</u>
The first process is called “Problem definition” and it contains three aspects:

1) Scope definition
The analyzer must understand the scope of the work, such as the scope of SW or HW that needs to be detected. A clear definition of the scope is important, since the analyzer needs to get a clear understanding of the cost elements, which forms basis for predicting the total LCC.

2) Evaluation criteria definition
Costs are not an independent entity, costs needs to be added with the "effectiveness" of the overall system. The effectiveness contains system characteristics, such as product quality, product capacity etc.

3) Operation philosophy development
The operation philosophy could, as an example, mean that the maximum available resource should be given to maintenances. Operation philosophy such as operational requirements or maintenance strategies should be defined in this process while conducting LCCA.

Process 2: Cost elements definition
The target of LCC model is to identify all the relevant life cycle phases. "Cost breakdown structure" and "cost categories" needs to have the boundaries to avoid omission or duplication. An example, taken from BS EN 60300-3-3:2004 Dependability management Application guide, can be seen below and in figure 4.

1) Cost breakdown structure (CBS)
It will define all the cost items which will influence the total LCC analysis. According to an international standard of LCC, CBS maybe separated to three axes which are "life cycle phase", "product/work breakdown structure" and "cost categories". How they are connected to each other can be seen in figure 4.

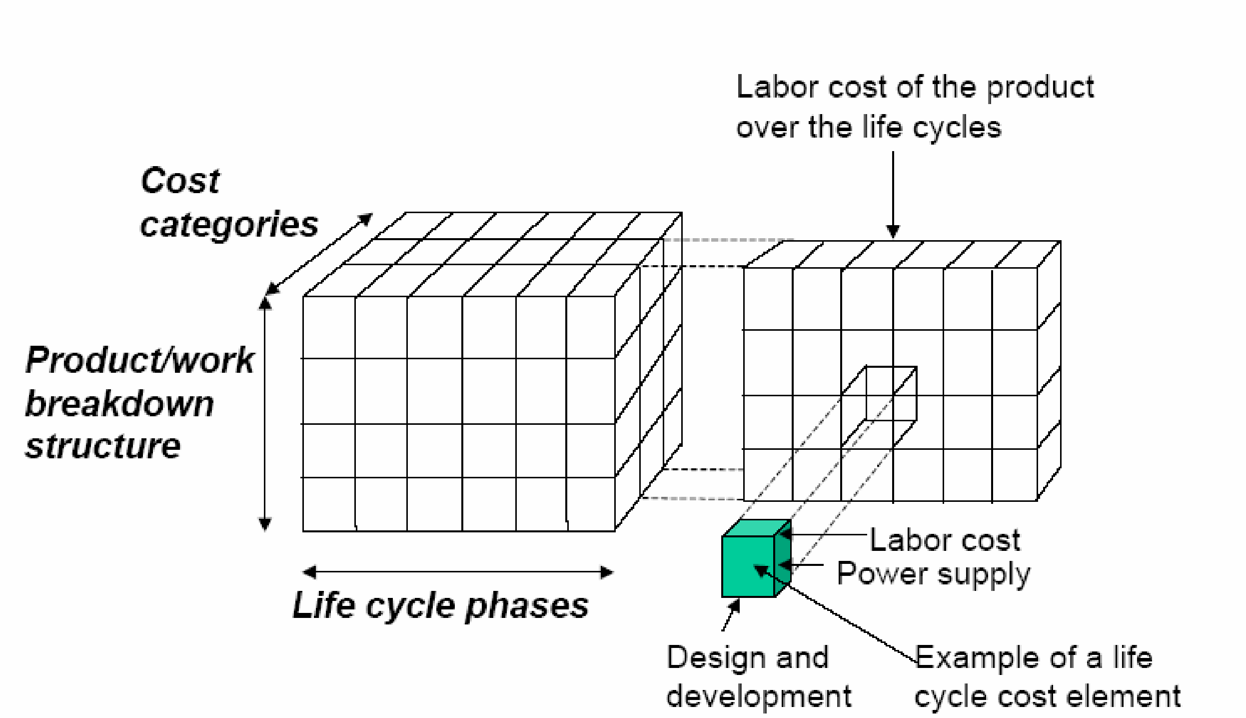


Figure 4 - An example for life cycle costing model [39]

This matrix involves the identification of the following aspects of the product:
• Product/work breakdown structure: it includes the cost categories of applicable resources such as labor, materials, and energy.
• Cost categories breaks the asset down into lower levels
• A life cycle phase is the time when the whole work/activity is to be carried out.

2) Cost categories definition
LCC analysis can be applied to many different types of system, it is therefore not simple to define the cost categories. A specific definition of the cost categories will only be used in a limited area. Some cost categories on the highest level will, despite this be used in many LCC analysis, e.g. “Acquisition costs” and “ownership cost”. For example, a reference[40] defines three cost categories on the highest level of the CBS, which are “Acquisition cost”, “Operating cost”, and “Cost of deferred production”

Process 3: System modeling
After the definition of the cost categories, the cost must be quantified in the LCC analysis. This is done by building a model that finds the relationship between the input data, input parameters and the cost categories.
In general, a model should be set up from these aspects, such as availability, maintainability, logistics, human error in the system, etc.

Process 4: Data collection
Accurate input data is crucial to improve the analysis of the LCC. The input data can be of two different kinds, depending on the availability; actual data or estimated data. When actual data which is related to an analyzed system is not available, the data may be estimated.

Process 5: Cost profile development
A cost profile, in the affordability analysis, over the whole life cycle is a key element. The cost profile of each design case should be based on a common reference point. The development of the cost profile is achieved by using the running cost model developed in the LCC analysis.

Process 6: Evaluation
If the system or product does not match the requirement, it should be modified as an alternative system, and then evaluated. During the evaluation process, the uncertainties of the input data should be considered. The evaluation consists of two parts which is sensitivity analysis and uncertainty analysis

Process 7: Optimization
Optimization is the final process and the analyzer is looking for the best solution. In a broad sense, optimization is to find the parameters which can minimize the LCC of the total system. In a narrow aspect, the optimization can be considered as a sub process e.g. a design optimization.

4.2.4 Could LCCA be applied to solve the problem?

LCCA is theory on how to lower costs by calculating the total cost of ownership. The authors established in the first chapter that high quality leads to savings, which are often converted into revenues. Costs are therefore closely connected quality but LCCA can not be directly applied to the problem. It has the characteristics of a theory and methodology and LCCA is more focused on how workers should think in different cost or quality related situation. Less focus has been placed on the actual detailed method of establishing poor quality or high costs. LCCA could still be made useful since it has been used as inspiration and used as base for analyzing the A&W models. Watchdog does not, unlike Argus, perform any analysis based on costs or quality points and can therefore not be analyzed with the LCCA. For the A&W models, the authors did not consider the overall life time for SW and HW quality, however, the process for LCC can be used to analyze Argus. This analyzing section can be found after the presentation of Argus.

4.3 Six Sigma

4.3.1 General information on Six Sigma

Sigma was developed by Motorola Company in 1986 to improve production by eliminating defects. It is using a systematical process, a methodology and a management system. Six Sigma uses a number of tools to ensure high quality and it is the current situation or process that determine which will used. The success of Six Sigma has had a deep influence and was responsible for a build up of an effective infrastructure in the entire world. It has not only become an important part of Total Quality Management, but also one of the most frequently reported trends in business community during the latest years. The users of Six Sigma is striving to have less than 3,4 defects per 1 million produced products.[41] The UK Department for Trade and Industry says Six Sigma is:

"A data-driven method for achieving near perfect quality. Six Sigma analyses can focus on any element of production or service, and has a strong emphasis on statistical analysis in design, manufacturing and customer-oriented activities." June 2005.

Key concepts of Six Sigma:

1) Avoid failing to deliver what the customer wants.
2) Find the attributes most important to the customer.
3) Determine what your process can deliver.
4) Invesigate what the customer sees and feels.
5) Ensuring consistent, predictable processes to improve what the customer sees and feels.
6) Designing to meet customer needs and process capability.[42]

Six Sigma can be said to consist of 3 parts:

- DMAIC: Define, Measure, Analyze, Improve and Control
- DMADV: Define, Measure, Analyze, Design and Verify
- DFSS: Desgin for Six Sigma

DMAIC is used improve an existing process, for example a business process. DMADV is used when a new product is being developed and the producer wants to improve the products predictable and make it defect free. DFSS has another purpose and that is to determine the customer's need and implement them into the product.
DMAIC has the following methodology and its part are:

- Define the improvements that need to be done in order to meet customer needs.
- Measure the current process and collect relevant data.
- Analyze the data to determine causality factors and determine what the relationship is, and try to make ensure that all important factors have been considered.
- Improve the product based upon the conducted analysis.

- Control the deviations so that they don't result in serious defects. Set up pilot runs to establish process quality and measure continuously after production.This is when the producer wants to maintain a low level of defect products.[43]

DMADV has the following methodology and its parts are:
- Define the goals of the design so that the demands of the customer are taken into account, but without jeopardizing the company strategy and its goals.
- Measure and identify things that are critical to quality, such as product capabilities and risk assessments.
- Analyze and create alternative solutions via high-level design and select the best choice by evaluating the design capability.
- Design the low-level details so that the design gets optimized.
- Verify the design choices by setting up pilot runs and implement the production process. Final step is to handover the process/product to its owners. [43]

Quality tools that are used in order to follow the methodology are numerous and choice of tools depend on the specific situation. The following list contains a few of the them:
- Control Chart: Monitors variance over time and alerts the analyzer when unexpected variance occurs which may result in poor quality.
- Defect Measurement: Counting the number or frequency of defects that creates faulty products or results in poor service quality.
- Pareto Diagram: Focuses on the problems that can lead to the biggest improvement by focusing on the problems with the highest relative frequency. This statement is based on the Pareto principle that states that 20% of the sources cause 80 % of any problems.
- Root Cause Analysis: An analysis is made to search for the deviation from the desired value and find the reason behind the unwhanted value.
- Statistical Process Control: This model is used when the analyzer wants to study and monitor process capability and performance by using statistical methods. This part will be described in further detail in section 4.4.
- Tree Diagram: Each goal is broken into different layers with specific actions associated with it. This tree encourages team members to expand their thinking "outside the box" when they encounter problems.[43]

4.3.2 Could Six Sigma be applied to solve the problem?

Six Sigma can be said to act as a theory or a problem solving approach instead of being a detailed model on how to exactly deal with quality problems. DMADV is used during the planning stage before a company starts production and it is therefore not suitable to use as tool to solve the problem. The data needed for DFSS (customer requirements) is not present in the RBS ISP Tool and DFSS could not lead to any direct results when applied to the problem. DMAIC has a couple of aspects that could be interest when trying to solve the problem. Measure and Analyze would be parts of great importance when dealing with input data from RBS ISP Tool. The Six Sigma methodology doesn't state exactly which tool an analyzer should use but it gives suggestions and they are:
- The control chart could be used to detect alarmingly high values .i.e. when a value is above a maximum limit.
- Defect Measurement could be a technique to measure and detect trends on the number of above a maximum limit.

- Pareto Diagrams and its relative frequency could be used to detect problems affecting only a small part of a big population.
- Root Cause Analysis would be needed to see which fault code that is to blame for a revisions poor performance.
- Statistical Process Control could give a statistical dimension to a large amount of data. SPC way of dealing with the problem will be discussed in greater detail in coming sections.
- Tree Diagrams wont be used in any form since the authors wont be dealing with the problems that arises when trying to encourage personnel to reach certain goals.

The former list with its contents will be used as a guide and inspiration when constructing the A&W models. Six Sigma in it self cannot solve the problem since it is not a model but it can contribute by highlighting some vital aspects of quality monitoring. These findings will be incorporated in the created models. Six Sigma could be a very efficient tool when producing the individual parts to each component within a cabinet. If a component, such as the DXU, would consist of 10.000 parts and you would expect that 3,4 DXU of 100 would be defective. 96 defective free units per 100 can not be deemed as an acceptable level. This means that Six Sigma might be to unstrict, eventhough the goal of only 3,4 defective part per million appear to be unreachable. If the fault is connected to a SW, then the mapping between software fault and failures is not one to one, it is many to many. This would complicate things and make calculations on the level of defective parts per million almost impossible. The complex behavior of a cabinet makes it impossible to measure all faults, only a limited number of faults can be measured and thereby translated into failures. Even though the RBS ISP Tool contains nearly 400 fault codes, that number is much too small to give a complete and final picture of the quality if Six Sigma would be applied.

The authors don't believe that Six Sigma would be directly applicable to the problem, but if Six Sigma were applied to the problem and companies in general, then the advantages would be;

- It is a general methodology that can be applied on many different quality areas and thereby improve the status for searching for poor quality.
- A company, like Motorola, has report huge savings since they adopted Six Sigma.
- Customers and their needs are prioritized.
- All steps from start to finish are covered in DMADV and DMAIC.
- Numerous tools exist to improve quality when a company has decided to adopt the Six Sigma methodology.

and disadvantages would be:

- Six Sigma is only a methodology and are not a model that can be used directly to improve quality.
- The generic models proposed as tools would need further development before explicit data from the RBS ISP Tool can be applied.
- According to the Fortune Magazine, many of the companies that have adopted Six Sigma have trailed the S&P 500 (a list of the 500 most succefull companies in the USA).

- Numerous tools can be confusing for a prospective customer who wants to try Six Sigma and it only functions properly when measuring quality on simple and individual parts.
- Only faults revealed by failures, such as those that are covered by the RBS ISP Tool can be used as base for improving quality.

4.4 Statistical Process Control (SPC)

SPC is one of the tools listed in Six Sigma and this model will be presented in further detail than the rest, since it exhibits great similarities with A&W. The resemblances, except that they are quality measuring models, are:

- Both models and SPC forms a ground for ending a process if it is considered to be out of control and both might need external analyzers to find the root cause.
- SPC and A&W use historical data and don't focus on individual parts.
- Argus, the Watchdog and SPC use graphs to illustrate the results to help the analyzer visualizing the current state.

SPC and A&W have obvious dissimilarities but their main features can still be analyzed from a comparison point of view. Argus and Watchdog are more specialized because it must use data from RBS ISP Tool, compared to SPC which functions on data from all directly measured merchandise. A&W measure quality indirectly by using statistics from the number of alarming TGs.

The authors will start this chapter with a historical background and then go into further detail in the following sections. SPC contains a great deal of statistical terms and the authors won't go into any mathematical details, since it lies outside the scope of this thesis.

4.4.1 SPC background

SPC was developed by an American named Walter Shewhart in the year 1923. It was first published in a book called *Economical Control of Quality of Manufactured Products*. The technique was based on Shewharts understanding regarding differences between random variations and systematic variations within a manufacturing plant. He believed that random causes must be accepted and that normal variations give us a yield. A yield is a normal spread that results from any process. The SPC-technique died out during the Second World War and even though it was used in the USA and Europe during the 1950s, 1960s and 1970s it never became established as a prioritized technique. When the Japanese launched their new production philosophy they looked at several quality models and the one that especially caught their attention was Shewharts model. The Japanese changed a fundamental part of his theory so that it would fit better with their overall culture and this was that they wanted the operator to perform all measurements and calculations. They could then, instead of inspection personnel, steer the production towards higher quality. This SPC way of using Shewharts technique gave birth to Statistical Process Control. The new way of doing things rapidly became a recipe for success and soon the marked was flooded with high quality merchandise at low prices from Japan. SPC also became a root cause for a change in attitude and corporate culture. The production worker became responsible for the quality and it became every workers obligation to improve quality in every part of the production process. America started using SPC again when they, during the 1970s, once again realized its potentials and Europe and Scandinavia started using the model during the 1980s.[44]

4.4.2 Basic features of SPC

There is a risk for over- and under control when you only use tolerance limits as a quality measure. Under control is when you do nothing even though it might be necessary to alter the process and over control is when the operator adjusts the quality when it is unnecessary. Target value steering means that you instead of focusing on individual parts, you focus on the location of the production yield.[45] A company that can produce the bulk of its products near the target value will produce high quality products in the cheapest possible manner. A close proximity to the target value means that the products have a high margin of safety to the tolerance limits. A high margin means that very few of the products will have to be thrown away or remade. When the operator measures his parts he doesn't care if a few are outside the tolerance limits, the most important part is that the mid-point (its location / mean-value) of all that is produced is as close to the target value as possible. The spread of the production (the width of the yield) is also an indicator of the overall quality.[46] If the operator measures the spread and compares it with historical data and finds big anomalies, he can then order that quality enhancing maintenance is to be conducted on the machine. Parts that are outside the tolerance limits could very well be functioning but they aren't working perfectly. So in order to minimize future inspections, costs and discarded products the operator needs to focus on the target value.[47] All numbers that are specified in the text regarding SPC have been found by using statistical calculations.

4.4.3 Reasons for using SPC

The principle motive for the majority of the companies applying SPC to their business processes is to improve customer satisfaction and reduce business costs. It guides them to improve the functioning of the process and thereby increase revenues. SPC in it self will not make improvements, rather, SPC will give analyzer a tool to identify when a special cause of variation has entered the process. The special cause must be eliminated (if a result is signalled by a control chart as being due to a special cause) or built into the process (if the special cause has a positive impact on the process). In addition, SPC can be helpful in identifying opportunities for improvement that can lead to reduced variation and processes that are better aimed at their target. The different types of charts play an important role in the improvement process.[48]

4.4.4 The Graph method

The yield almost always looks like a normal distribution[49] and the spread is normally six standard deviations, and that is around 99,73% of the entire yield. The most common divergences from this normal distribution are skewness (asymmetrical yields) and multiple peaks. A normal distributed curve can be seen in figure 5.

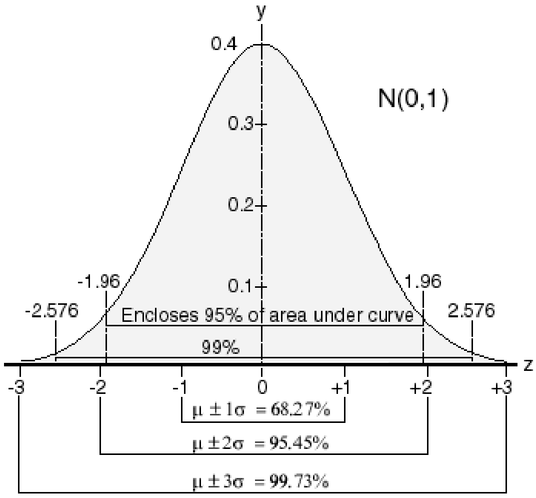


Figure 5 - Samples that are normally distributed

A test when you compare a yield with the specified tolerance limits is called a capability test. For this test the operator need to sample 20 – 100 items in a consecutive order. The operator will preferably hold other variables (such as temperature or machine settings) constant in order to make a proper analysis of the current production. The items are divided into classes and the number of classes should not exceed 8. An example of classification could be a measurement of the diameter and each class should have a percentage value. The next step is to plot these values in a graph and if the values form a straight line in the capability test, the machines products can be described with a normal distribution. This graph can been seen in figure 6. The lower and upper tolerance limits (LTL & UTL) and the total spread of the machine yield is also printed in the graph (+/- 3 standard deviations). The operator can with this method, by using only a small sample, tell if the machine meets the tolerance limits. The mean value (50%) is also plotted in order to see location of the production yield. See figure 3 for an illustration. If the values don't form a straight line, then the operator will have to accept that the machine yield is not normally distributed.[50]

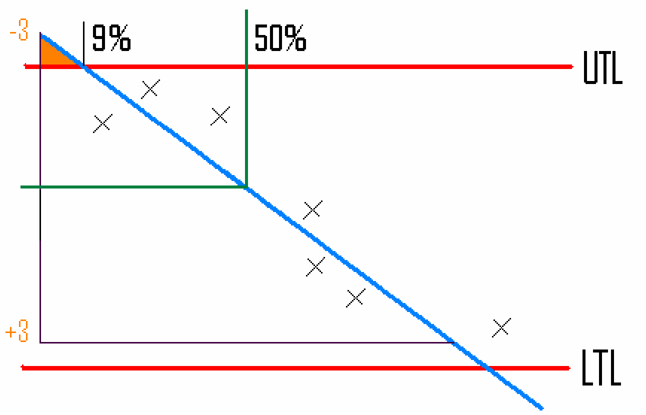


Figure 6 - Normal distributed values plotted in a graph[51]

One way of determining if the machine is capable is to calculate the Machine Capability Index (Cm , equation 7). The variables in formula is tolerance width (TW) and machine spread (MS).

$$Cm = \frac{TW}{MS} \qquad (7)$$

A Cm value which is less than 1 translates is an indicator that some of he products that are outside of the tolerance limits. When the value is equal to 1 the tolerance limits are just met. If the machine is producing products that are well within the tolerance limits the Cm value will be higher than 1. A Cm value which is in the range of 1,3 - 1,5 or more gives a good safety margin when conducting these tests in a factory.[52]

4.4.5 The Control chart

"Failure to use control charts to analyze data is one of the best ways known to mankind to increase costs, waste effort, and lower morale."
---Dr. Donald J. Wheeler

The previous graph method is a good way of describing the basic features of the SPC. The overall goal of SPC is to adjust the location of the yield to the target value and this is often made by using a control chart. The analyzer samples the data at regular intervals and plots them in the control chart. A green line is added in the middle of the chart and it represents the mean value ($\overline{\overline{X}}$). Instead of using tolerance limits, which are used to indicate if the products are good enough for delivery, the analyzer draws control limits (CL) and a normal value for these are +/- 3 standard deviations.[53] These limits are coloured red and are used as a source for making decisions, when the process might need adjustments. As long as the values are within these control limits, the authors can assume that the process is under control and that the target value has been met. It is the process itself which decides what control limits will be used. If the analyzer has steered the process so that the mean value is between the control limits and as close to the target value as possible then the process is working to the fullest of its capacity. 5 samples are enough for an accurate mean value. The target value can be chosen by the analyzer or calculated from previous tests. An example of a control chart could look like figure 7.[52]

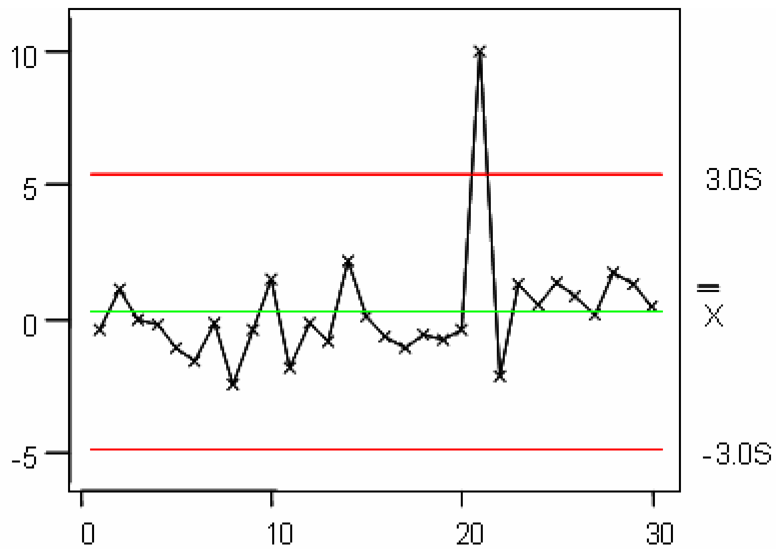


Figure 7 - A control chart with a mean value and control limits [54]

If one of the mean values exceeds the control limits, the analyzer can be pretty sure that the target value has not been met. Many of the products are in this case being built on one side of the target value and the analyzer has to adjust the process in order to compensate for the difference. If the analyzer corrects the process before the mean value is outside the control limits, the process is in danger of being over controlled. It is therefore better to wait before the analyzer has substantial evidence, in this case a mean value outside the CL before he starts correcting. One important factor is to keep the time between the samples appropriately small, if the sampling time is bigger than optimum the process is in risk of risk becoming hard to control and keep near the target value. The optimum time depends on what types of products are being made in the process. [52],[54] By instable Johonson & Tisell means that one mean value is outside the control limits. The analyzer should then immediately try to perform correcting procedures and make a note on the control chart about what has occurred and what actions followed if a value was outside the CL. If the process becomes too instable, it might be necessary to stop it and hand over the information to external professional analyzers.

Another important factor to monitor is range (R), which is the difference between the largest and the smallest value and a spread chart with shows a range can be seen in figure 8. The mathematical formula for the range (8) is:

$$R = X_{\max} - X_{\min} \tag{8}$$

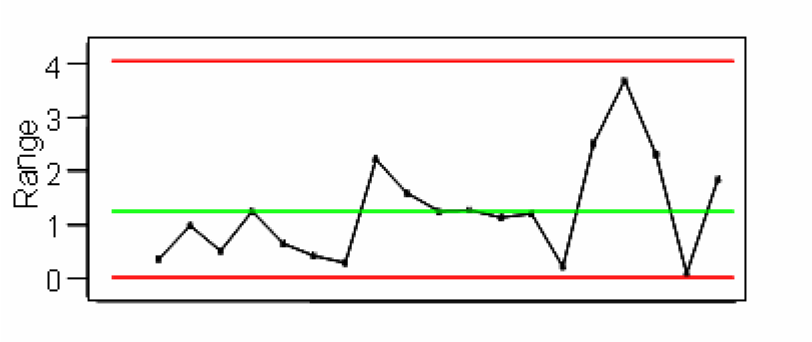


Figure 8 - A spread chart which shows a range [54]

If the sample size is 5 items, then the range shouldn't be more than 40% of the spread. A higher value could indicate that the spread has become bigger and that the machine or equipment needs adjustments. A higher sample value than 5 requires also a minimum range (R_{min}). It is important to note that it is impossible to know what happens between the points in the control chart because the lines are only there to simplify the task of finding trends. When evaluating the control chart, there are several things to look for:

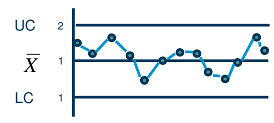
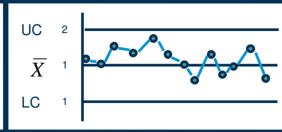
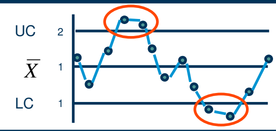
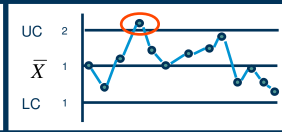
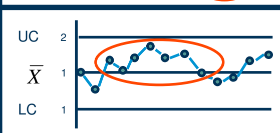
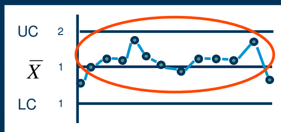
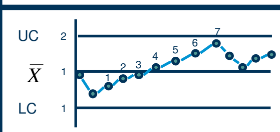
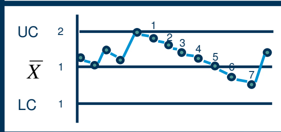
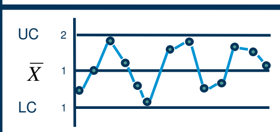
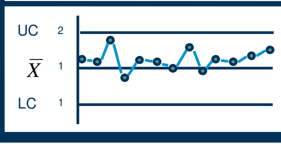
Chart	Description	Example #1	Example #2	Interpretation
Process In Control	Chart points do not form a particular pattern AND lie within the upper and lower chart			The process is stable. Doesn't necessarily mean that you should leave the process alone. Might exist be opportunities to improve the process and enjoy substantial benefits.
Process Out of Control	Chart points form a particular pattern OR one or more points lie beyond the upper or lower chart limits.			Alerts you that the process is changing. Might be related to a change you have made. Be sure to identify the reason(s) before taking any constructive action(s).
Run	Chart points are on one side of the center line. The # of points in a run is called the length of the run.			Suggests the process has undergone a permanent change and is now becoming stable. Often requires that you recompute the control lines before future measurements.
Trend	A continued rise or fall in a series of points (7 or more consecutive points in the same direction).			Often seen after some change has been made. Helps tell you if the change(s) had a + or - effect. May also be part of a learning curve associated with some form of training.
Cycle	Chart points show the same pattern changes (e.g., rise or fall) over equal periods of time.			Often relates to factors that influence the process in a predictable manner. Factors occur over a set time period and have +/- effect. Helps determine future work load/staffing levels.

Table 1 - Characteristics of a control chart [55]

The characteristics can be found in the spread chart and should also be thought of when analyzing the spread chart. If 7 points are above/below the target value, the mean value has probably moved away from the target value. The process is then out of control and needs adjustments. The R_{max} and control limits need revising at regular intervals and if the charts are handled properly the process should become more stable. If the control limits are +/- 3 s (standard deviations) then there is only a 0,135% chance of finding a value outside these limits if the location of process is unchanged. There is a 50% chance that a point is on the same side as the previous one. This means that: P(7 consecutive points) = $1 * 0{,}5^6 \approx 0{,}016$. This means that the probability of an unchanged location is only 1,6% if there are 7 consecutive points on the same side of the mean value. These calculations filter out the random causes and locate the systematic ones.[52] Random causes can also be described as common causes (noise) and they are a result of "the way we do business" and process changes focusing on these has to be fundamental. Systematic causes are also called special causes (signals) and are caused by unique disturbances and can be dealt with by basic process controlling and monitoring.[55]

Additional limits can be used to further simplify the management of the process. Such limits are called warning limits. A common warning limit is 2 s and only 5% of the points will be beyond this limit if the samples form a normal distribution. The probability of finding two consecutive points between the warning limit and the control limit is: P(2 consecutive points) = 0,05 * 0,025 = 0,00125. This means that the probability of finding two consecutive points in this sector is only 0,125%.[55] Ericsson uses a set of rules, together with warning limits, in order to determine if the process is under control. If one of the rules is broken then something unusual might have happen and an analysis is required. The Ericsson rules are:

- Rule #1: One point outside the UCL or LCL (3σ limit)
- Rule #2: Two of three consecutive outside the 2σ limit

- Rule #3: Four of five consecutive outside the 1σ limit
- Rule #4: Eight consecutive on one side of the centreline
- Pattern Rule: A pattern repeats itself [55]

Rules can prevent the model from becoming subjective but also limit an analyzers freedom. If the general idea and the warning limits are followed, then SPC can be considered to be a powerful tool for measuring quality.

4.4.6 Could SPC be applied to solve the problem?

SPC is a tool for measuring quality by using statistics and it focuses on products that only require simple measurements i.e. the width of a pole. Quality becomes a much harder thing to measure and define when dealing with complex equipment, like a RBS. The authors have chosen to use a quality-definition that uses the number of alarming TGs as a base for determining quality. The RBS ISP Tool measures quality indirectly by storing data regarding faults that have resulted in alarms. Each alarm and fault code can be an indication that something is wrong with the quality, but it is not as definite as when you have defined quality as a specific width. The measured products, when using SPC, has to have a target value and control limits. In complex products, with alarming TGs, the target value can be said to be zero alarms. No lower limit exists and the only available upper control limit is the maximum limit, because it is beyond the purpose of this thesis to find another limit by manipulating the RBS ISP Tool. The authors could have incorporated an adjustable upper limit but the models must work properly without any prior modifications of the limits, and that is not the case when using maximum limit as the control limit in SPC. If the creators of the models would need to find a better working limit than the maximum limit before the analyzer can use the model, they would go well beyond the scope of the thesis. If the predefined maximum limit would be used as UCL, then all most all revisions will be chosen instantaneously, since almost all revisions have at least one fault code that are above maximum limit at any given time. A weighting function could keep the level below the maximum limit for each specific fault code until poor quality exists, but that solution would be equal to alter all maximum limits in the RBS ISP Tool before using the model.

The SPC has been determined by us to be a none-suitable model to use when analyzing RBS ISP Tool data. The main reason is the upper control limit and it has been discussed in detail in the former section. Another reason for its insufficiency is that it can only perform a lower level analysis on individual parts and not on complex items such as entire cabinets. Yet another problem is that SPC analyzer must hold other variables constant in order to get a good reading of the current situation. That is something that the ISP Tool analyzer can not do, since he isn’t in control of the other variables in the filed were the cabinet is located and every situation can therefore be said to be unique.

There are still advantages with the model when dealing with problems that are similar to the one that A&W are going to solve. These advantages will be used as inspiration when constructing the models.

- SPC looks continuously at historical data and that could be of great interest when trying to find trends or shifts.
- The rules, except the one with the CL, can be extracted to facilitate the analysis.
- The use of charts increases the validity, since it is then more likely that the analyzer focuses on the correct problem area.

- The rules provide the same result no matter how many times the process is monitored or who is monitoring the process. This is something to strive for and it is good way of increasing the reliability.

5. Techniques that form the analyzing base in A&W

Several techniques will be used to analyze the data from the RBS ISP Tool and they range from establishing a moving average, create equations and charts. The following chapter will contain teqniques that are vital for the created models.

5.1 Moving Average

> *"I like to think of statistics as the science of learning from data...It presents exciting opportunities for those who work as professional statisticians. Statistics is essential for the proper running of government, central to decision making in industry, and a core component of modern educational curricula at all levels."*
>
> --- Jon Kettenring, ASA President, 1997

Statistics is a mathematical science .The Merriam-Webster's Collegiate Dictionary® definition is: "A branch of mathematics dealing with the collection, analysis, interpretation, and presentation of masses of numerical data."

When an analyzer is faced with lots of random variation, the first thing the analyzer need to do is to calculate an average or the arithmetic mean. In statistics, moving average is a vital technique that is used to analyze data in a specific time period. It is used to smoothen out short-term fluctuations and then highlighting longer-term trends or cycles.[56] Figure 9 (below) shows a moving average chart.

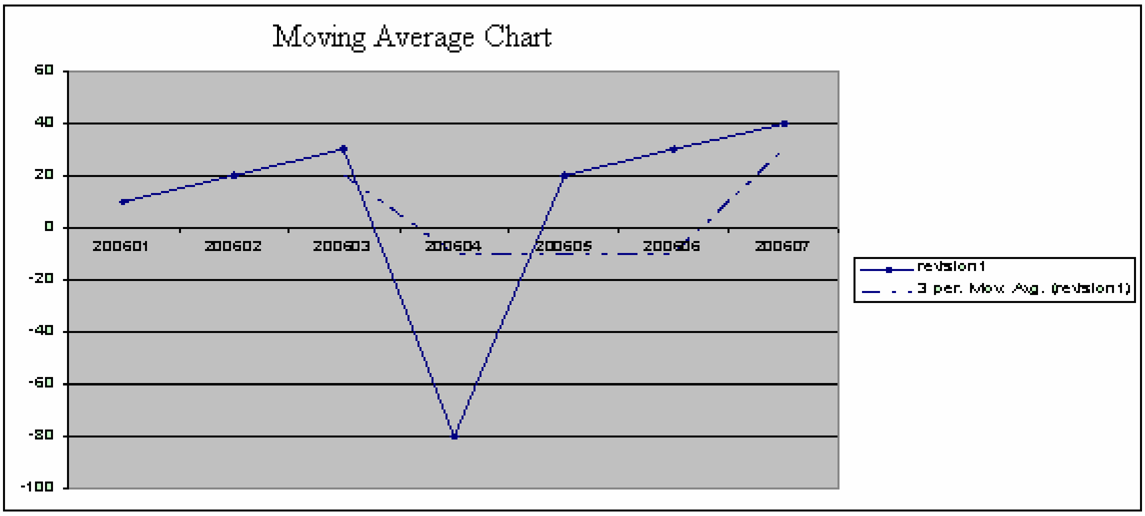


Figure 9 - A moving average chart

The categories of moving average are:

1) Weighted moving average
2) Exponential moving average
3) Simple moving average

5.1.1 Weighted Moving Average (WMA)

WMA is an average that has multiplying factors to give different weights to different data points. The weights are decreasing arithmetically. In the n-day the WMA, equation 10, has weight n, the second latest n-1 and so on down to zero.

$$WMA_M = \frac{nq_M + (n-1)q_{M-1} + ... + 2q_{M-n+2} + q_{M-n+1}}{n + (n-1) + ... + 2 + 1} \tag{10}$$

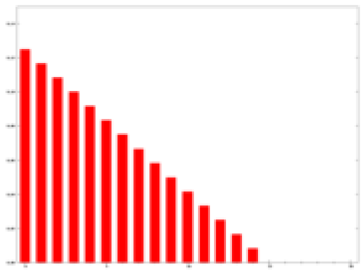


Figure 10 - WMA: weights n=15

Figure 10 (above) shows the weights decrease for the most recent data and down to zero.[57],[58]

5.1.2 Exponential Moving Average (EMA)

The weighting in EMA, equation 11, decreases exponentially for each day and are tereby giving greater importance to recent data, while still not entirely discarding older data. The figure 11 (below) shows an example of the weight decrease.

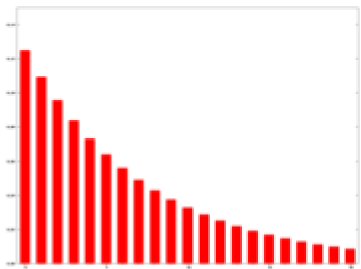


Figure 11 – EMA: weights n=15

$$EMA = EMA(t-1) + \left(\frac{2(Xt - EMA(t-1))}{n+1} \right) \tag{11}$$

n = the length of the Moving Average
x = Price of the symbol [59],[60]

5.1.3 Simple Moving Average (SMA)

SMA, equation 12, is an un-weighted average of the latest *n* data points. “Moving” is a way of referring to it as a sliding window along the curve, with an average over last n days for every day. As the number of data points in the moving average increases, the curve becomes smoother, since day to day fluctuations are increasingly averaged out. The moving average lags behind the actual trend, since the average includes historical data.

$$SMA = \frac{q_M + q_{M-1} + \ldots + q_{M-4}}{5} \quad (12)$$

q stands for the quality value.[61]

5.2 Quality charts

Quality is based on customer's satiety. If the products or services deviate from this target, customers will detect this changes and perceive bad quality. Therefore, assuring good quality can be seen as a balance between customer satisfaction and company profit.
Lessons that can be drawn from the models charts are interesting for the design and market department.

Shewhart proposed the use of control charts as a useful analysis tool to monitor the consistency of product. Bar charts are used to present data with the highest cost for the latest month or the fault codes with the highest values compared to a limit or average. In A&W, Run charts are used to monitor the 3 year's trends, shifts or patterns that occur in different revisions.

5.2.1 The Run chart

A run chart is a graph that shows data in a time sequence. The chart often shows the performance of the product or some business process. Run charts are analyzed to find the anomalies in a time period that suggest changes in the whole process.[62] Run charts originated from control charts. However, a control chart focuses more on acceptable limits (control limits) and run charts focus more on time patterns. In run charts, time is usual represented on the horizontal axis (X axis) and the value of the product under observation is on the vertical axis (Y axis). The axis and a data example can be seen in figure 13. In some cases, measures of central tendency such as relative difference, absolute difference and mean value of the data is indicated by the "0" reference axis. Run charts are used to visually detect when something has negatively affected, for example, the quality. Run charts can be analyzed according to similar rules as the control charts. Shifts, trends and patterns in the run chart might be identified if the analyzer takes the following rules into account:

- Shifts: seven or more consecutive points on one side of the center line.
- Trends: six consecutive jumps in the same direction.
- Pattern: a pattern that recurs eight or more times in a row.[62]

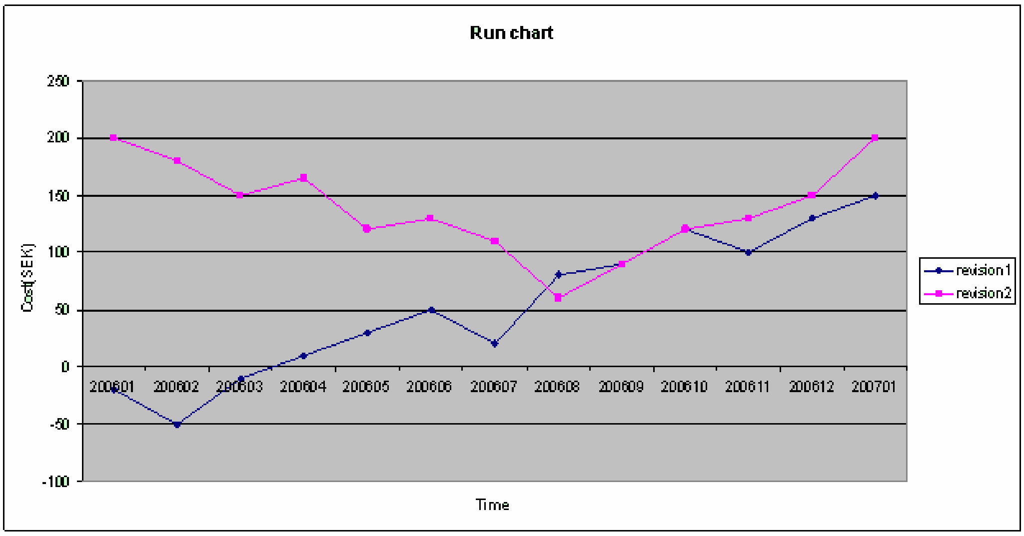


Figure 12 - An example of run chart

In this example (figure 12) of a run chart example, X axis is representing the time form 200601 to 200701, Y axis is representing the cost (SEK) and the run chart shows the cost variation for 2 different revisions in 13 month time period.

5.2.2 The Bar chart

Bar chart is a chart with rectangular bars of lengths that are proportional to the magnitudes or frequencies of what they represent. It is used to present two or more data over a nominal (e.g. Money) or interval scale (e.g. time) and bar charts are useful for comparisons of data for a specific date.[63]

6. The contribution - Argus and Watchdog

The models that will be presented in this section are Argus and Watchdog. The exact way of finding the vital information will not be described, only the overall functionality, purpose and the contribution will be presented in this chapter.

One big model would have been tough to work with since the authors continually added new functions to each model. The number of possible errors that could occur when new code would was added increased if one single model was used. Many parts of the model are connected to other parts and it is therefore almost impossible to foresee how a small change or a new function would influence other parts. The incremental approach, divide a big problem into small ones, minimizes the number of possible errors as the models grow.

Another reason for making two models instead of one is that it was determined that it would be easier to analyze the results if the two different levels (fault code and revision) were separated. Both levels are important in their own way and they show different aspect of the same input data. One big model would have meant a high number of charts and functions that the analyzer would have had to deal with. This would have had put too much strain[64] on the analyzer and his or hers analysis of the results would have been compromised.

A&W are dependent on input data from RBS ISP Tool, in the form of Base data files and Result files. These files are then converted into Input files that can be analyzed by A&W. In figure 13 the flow of different types of files can be seen.

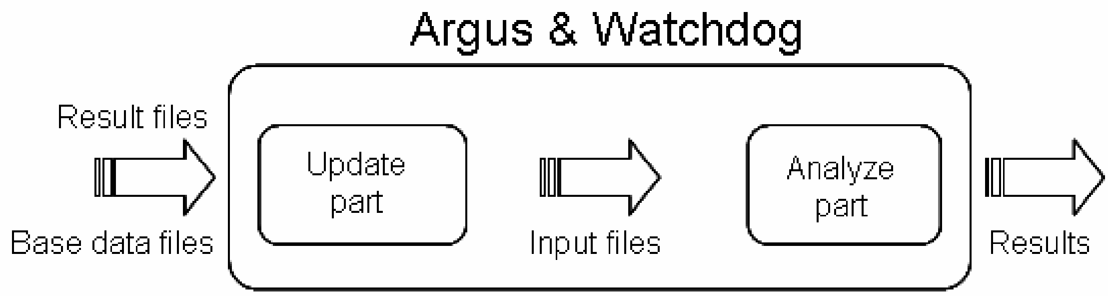


Figure 13 - How Argus & Watchdog uses files

The purpose of A&W are to detect the flaws and pinpoint the revisions and fault codes that are the big contributors to poor quality. They are supposed to work as a help instrument for the analyzers who conduct the quality controls. Instead of manually ploughing through paper after paper and comparing one revision against a couple of others, the models will do this exhausting work and lead the analyzer in the correct direction.

The purpose of the individual models is as follows:

- Argus will perform an analysis on a high level, for example on cabinet or revision level. Each fault code will get a quality point value and Argus will summarize the impact that each fault code has on the total quality.
- Watchdog will find negative changes and trends on fault code level. It focus merely on individual fault codes and compare the current value against a predefined maximum limit or a moving average.

The scientific benefits from the models are presented in each section and they range from flexibility, filter and weighting functions, updateability, visual and numerical presentation of the results.

6.1 Update part

Both Argus and the Watchdog use an update part which enables them to use input data from RBS ISP Tool. The similarities between the update parts are extensive and that is why this part will be presented before each models analyze part is described separately.

The purpose behind the update part is to facilitate the weekly updates, increase the models flexibility and make the models as automatic as possible. The ensure a good ability to find poor quality, the model has to be able to adapt to an ever changing world and be flexible. A static model that only would work on a limited amount of revisions would by considered useless after only few trials and that is why the coding has been constructed to be flexible and adaptive. The authors have identified four different cases that describe how the analyzer will use the update part. The four different cases are:

- The first case is when the analyzer wants to perform a completely new analysis.
- The second is when the analyzer wants to update the input files with new result files.
- The third occurs when the analyzer wants to add new base data files to the analysis.
- The last and fourth is when the analyzer wants to add both new result files and new base data files.

6.2 Argus

6.2.1 General information, purpose and description

The authors chose the name Argus since it is a mythical giant who according to a legend had 100 eyes. Argus was the perfect guard since he could always keep at least a couple of eyes open while he slept. He was appointed to watch Io, who had been turned into a cow by Hera, and let Hera know if her husband Zeus came near his beloved mistress Io. Zeus told Hermes to kill the giant and so he assassinated the giant with a big rock.[65] Like the giant, the model Argus keeps at least a pair of watchful eyes on the revisions that the analyzer has specified.

Ericsson is the most important category since it is Ericsson who will conduct the analysis and the only one who will have access to Argus. If the values in the QPI have been adjusted to a specific operator, then the values that are delivered by Argus can be used to increase quality for that operator. This would be good since it could increase Ericsson's revenues in the long run, if it could be used as a sales argument. The model could be used in the future to calculate on prospective customers and they would get a number on how they would benefit from switching from one supplier of cabinets to another. They would also be able to understand how much better the quality would be if they switch from one SW/HW revision to another. Argus is due to participate in a pilot project and if that has a positive outcome Argus will be used in other projects to measure quality for both Ericsson and operators. When the subjective values are used, the most annoying (from an Ericsson quality point of view) can be isolated for further analysis.

The purpose of Argus is to locate the revisions with the highest QPI score (lowest quality) so that a further and deeper analysis could be done on the one that requires the most attention. To facilitate the use of the model the authors have placed all vital functions in one control desktop. This enables the analyzer to focus on the analysis instead of finding the correct function among dozens.

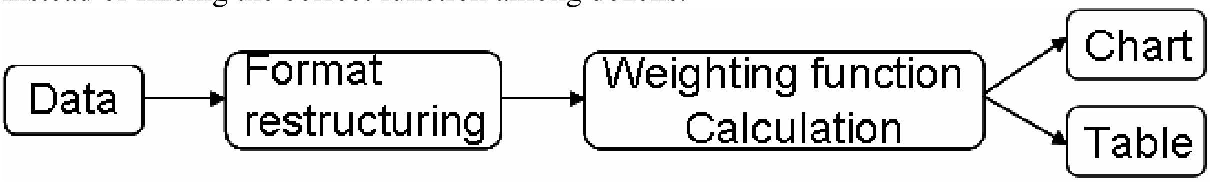


Figure 14 - Argus flow chart

The data in figure 14 is the input data and it comes from the RBS ISP Tool. This data needs to be restructured by the Argus before it can find the revisions that are responsible for poor quality. The update part of the model takes care of the restructuring that must take place since the input data comes in different shapes and needs to be converted into a standardized format, so that the Argus can perform its task. The analyze part of the model is the one that finds the essential information and it is done by a weighting function, the QPI, and calculations. The presenting part of the model is responsible for making sure that the analyzer can perform further analysis and benefit from the findings. The presentation is done in charts and calculation tables. The Argus model can be used for Measuring HW and SW quality by evaluating different revisions quality. The characteristics of Argus model:

- It can handle large number of input files at the same time.
- QPI is an innovative weighting method used in the model.
- It can contain a large number of categories at the same time which can offer an analysis from different points-of-view.
- Results are presented in a scientific way.
- It is easy for an analyzer to find the major contributors in different categories through analysis of the results.
- It is a good tool to measure the current situation and detect trends and shifts.
- The analysis is easy to update weekly or monthly.
- New methods to for analyzing the input data (e.g. new calculations) can be added if it is necessary.

6.2.2 Basic QPI calculations

The method used to perform the analysis in Argus is to combine the input files, which are generated from RBS ISP Tool, automatically with the values in the QPI. Individual fault codes can have different affect on different categories and that is why a predefined value is added to every fault code in the QPI.

The authors will use an example with two SW revisions to show how the basic calculations are done. For SW revision 1:

1) If fault code 1 has a tremendous impact on Ericsson, then a higher QPI point will be attached to it, which in this case is 100.

2) If fault code 1 has no influence on the Operator, then the QPI for this fault code 1 is 0.
3) If the magnitude of the annoyance of fault code 1 is small, then a smaller value will be added which is 10.

The authors have 2 fault codes in total in this example and the total influence for the revision is the sum of these 2 results. Note that the comparison can only be made within the same category between different revisions. Here the authors only chose 2 fault codes as an example, but the real input files will contain 392 fault codes.

Fault code	**Percent of TGs**	**Operator QPI**	**Ericsson QPI**	**Subjective QPI**
Fault code 1	0.2	0	100	10
Fault code 2	0.1	100	10	5
Result		**0.2*0+0.1*100=10**	**100*0.2+0.1*10=21**	**0.2*10+0.1*5=2.5**

Example : SW 1

Fault code	**Percent of TGs**	**Operator QPI**	**Ericsson QPI**	**Subjective QPI**
Fault code 1	0.1	0	100	10
Fault code 2	0.5	100	10	5
Result		**0.1*0+0.5*100=50**	**100*0.1+10*0.5=15**	**0.1*10+0.5*5=3.5**

Example: SW2

From the tables above:

1) The result for Operator in SW 1 is equal to 10 which are lower than that of SW 2 which is equal to 50.That means the quality for SW2 is worse than SW1.
2) The result for Ericsson in SW 1 is equal to 21 which are higher than that of SW 2 which is equal to 15. That means the quality for SW1 is worse than SW2.
3) The result for Subjective in SW 1 is equal to 2.5 which are lower than that of SW 2 which is equal to 3.5. That means the quality for SW2 is worse than SW1.

The following figure (number 15, see next page) shows the control desktop of the Argus model. It has been designed to facilitate the use of the model by increasing the speed by which the analyzer can use the model and to give the analyzer a better overview of the entire model.

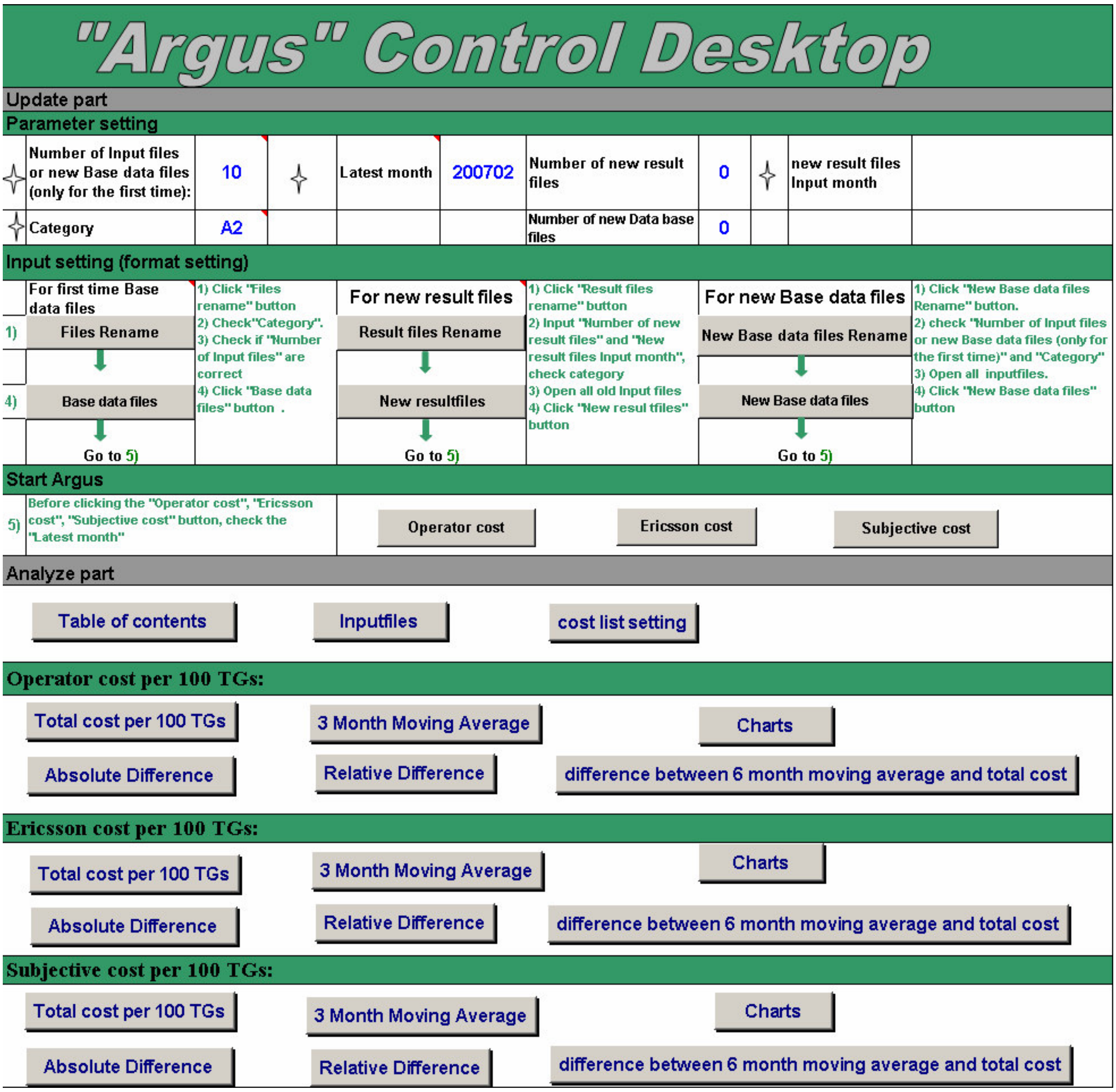
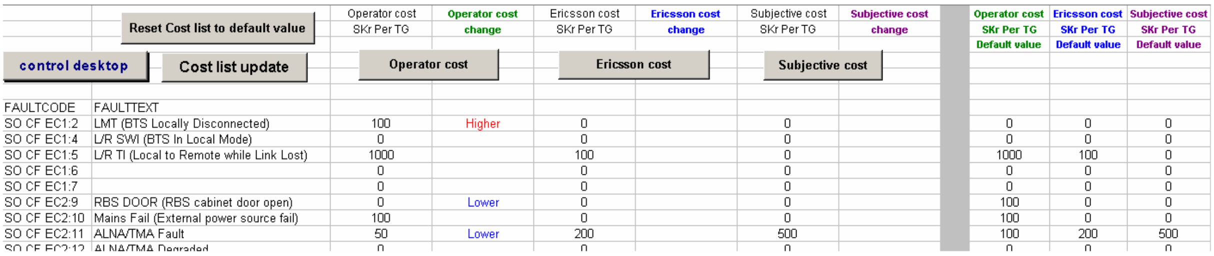


Figure 15 - Argus control desktop

6.2.3 Elements of "the analyze part" of Argus

"The input files" function shows which months that hold information and this could be very useful when the analyzer wants to update or change revisions. If the analyzer spots a revision in the function that he has planed to use in a coming analysis, he can keep that revision and avoid the process of converting a new base data file, of the same revision, into an input file. Updating the revisions with new result files becomes easier when the analyzer has total control over which months that contains information. The analyzer can easily see which revisions that require additional updates to complete his analysis.

Argus performs analysis on a higher level, i.e. on SW level, and doesn't look at specific fault codes. Argus pairs each fault code with a specific value in the QPI and then adds all these values to a total value per month and for each revision. The heart of Argus is the QPI and it is the weighting function (see figure 16) that enables the analyzer to see which revision is in the greatest need of assistance from a specific category point-of-view. QPI consists of 3 categories and they are Operator, Ericsson and Subjective. QPI share some common characteristics with “Max limit setting” or filter function in the Watchdog model. These values, as the maximum limits, controls which revisions the models will focus on. The analyzer can adjust the values in QPI depending on the situation or if he wants to examine how different values would influence the performance of the revisions. When the analyzer has done the changes in QPI that he believes would give an accurate description of the current state, he must then update this values by using the built-in update function. After this is done the analyzer can choose from which perspective he wants to perform his analysis. Each category can be separately analyzed or the results can be cross checked for a more profound understanding of the quality.



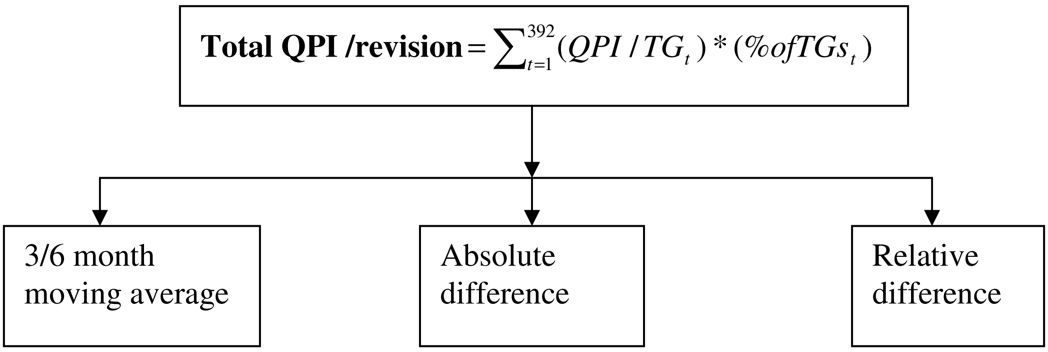
FAULTCODE	FAULTTEXT	Operator cost SKr Per TG	Operator cost change	Ericsson cost SKr Per TG	Ericsson cost change	Subjective cost SKr Per TG	Subjective cost change	Operator cost SKr Per TG Default value	Ericsson cost SKr Per TG Default value	Subjective cost SKr Per TG Default value
SO CF EC1:2	LMT (BTS Locally Disconnected)	100	Higher	0		0		0	0	0
SO CF EC1:4	L/R SWI (BTS In Local Mode)	0		0		0		0	0	0
SO CF EC1:5	L/R TI (Local to Remote while Link Lost)	1000		100		0		1000	100	0
SO CF EC1:6		0		0		0		0	0	0
SO CF EC1:7		0		0		0		0	0	0
SO CF EC2:9	RBS DOOR (RBS cabinet door open)	0	Lower	0		0		100	0	0
SO CF EC2:10	Mains Fail (External power source fail)	100		0		0		100	0	0
SO CF EC2:11	ALNA/TMA Fault	50	Lower	200		500		100	200	500
SO CF EC2:12	ALNA/TMA Degraded	0		0		0		0	0	0

Figure 16 - Weighting function (QPI)

The QPI influences the calculations that Argus uses to detect problem areas. An experienced analyzer would be able to extract vital information from mere calculations and data table since they contain information regarding quality points (or costs), revision name and month. The numbers given (Total costs and Moving average) should be enough to give the analyzer a good mental picture of the state of the revisions that he is analyzing. If the values in the data tables are not enough then the analyzer can turn to the charts and they are described in section 6.2.5.

6.2.4 Calculations performed by Argus

A couple of mathematical formulas will be used in the Argus model. They provide the basis to complete the quality detection. The total QPI can be considered as the basis of all the other calculation results in Argus.



4 important calculations will form the base for the analysis and they are:

1. Total QPI

It summarizes the QPI for every individual fault code. The following equation, number 13, is used:

$$\textbf{Total QPI} = \sum_{t=1}^{392} (QPI / TG_t) * (\% of TGs_t) \qquad (13)$$

t: the number of fault code.
QPI/TG: the quality point index for one TG.
% of TGs: percent of TGs which is above the maximum limit.

2. Moving average
The authors chose to use the simple moving average since it is sufficient for the task and is a good reflection of the way analyzers reacts to historical data. The moving average, equation 14, of total QPI is the average of the previous month's total QPI. The formula is:

$$\textbf{Moving average} = \frac{P_N + P_{N-1} + \dots + P_{N-(M-1)}}{M} \qquad (14)$$

M = the length of the moving average
P_N = total cost for a month

3. Absolute difference = (Total QPI - 3 month moving average) (15)

4. Relative difference = (Total QPI - 3 or 6 month moving average) / 3 or 6 month moving average (16)

The simple moving average has a very important role in A&W and their analyze part. Absolute difference is a good tool to analyze the difference between the total cost in a time point and 3 month moving average for a revision. However if you want to get a difference which is compared to the reference value, then relative difference is a good choice.

Revision	Total cost A	3 Month Moving Average B	Absolute difference [A-B]	Relative difference [A-B]/B
Revision1	200	180	200-180= 20	[200-180]/180= 11%
Revision2	5000	4980	5000-4980= 20	[5000-4980]/4980=0.4%
Revision3	100	80	100-80= 20	[100-80]/80= 25%

The absolute difference function lets the analyzer see if a specific revision is doing worse than normal. A value higher than the maximum limit is never a good thing and the one with highest value is a good candidate for further analysis. However it might be of less interest to focus on the one with a big absolute increase since fault codes with a high maximum limit are more likely to vary a great deal in absolute terms, compared to fault codes with a minute maximum limit. The authors decided, due to this predicament, to add calculations based on a relative difference.
From the table above, it is quite hard to choose a good revision with poor quality depending on absolute difference (all of these three revisions have a difference equal to 20), while relative difference can offer a good base for chosing.

If the analyzer would require further assistance, then Argus has predefined ways of examine the revisions and they are called *Absolute difference, Relative difference* or *Difference between a 6 month moving average and total cost.*

- *Absolute difference* is the difference between the total cost and the 3 month moving average. A positive value would indicate that the total cost is higher than the 3 month moving average and a quality reduction might have taken place.

- *Relative difference* has the same structure as *absolute difference*, the only difference is that the value is divided by the 3 month moving average to get an increase/decrease in %. The relative difference can pinpoint other revisions, i.e. the ones that normally have low absolute values but have a high relative increase. A positive value indicates a decrease in quality, since the values have risen compared to the 3 month moving average.

- The third way of analyzing the data is *Relative difference between a 6 month moving average and total costs*. This way of analyzing will look at a longer period of time and compare the latest value against how the revision has performed in average during the last 6 month.

6.2.5 The chart visualization of the findings

6 charts have been constructed to give the analyzer a chance get a good overview of the situation. The first two concerns highest total costs and highest 3 month moving average. Focusing on these values could result in a high absolute increase in quality if the root cause can be found. Chart 1 and 2 can be seen in figure 17 and all charts contain data regarding operator.

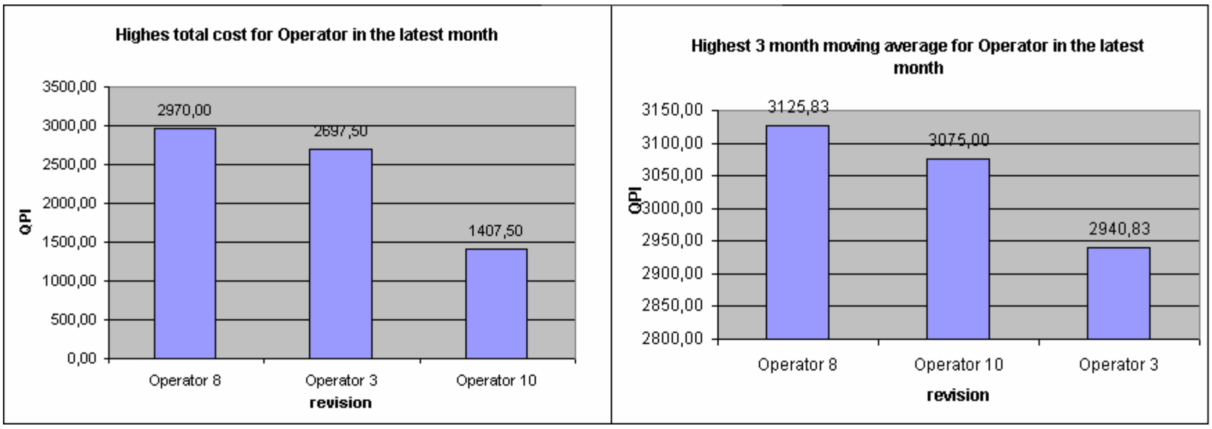


Figure 17 - Chart 1 Highest total cost. Chart 2 with highest 3 month moving average

Chart 3 (in figure 18) has historical data regarding highest total cost and moving average for revisions with the highest total costs. The trend can be analyzed in order to establish if the decrease in quality is part of a repeating pattern or if the quality is actually in a downward spiral.

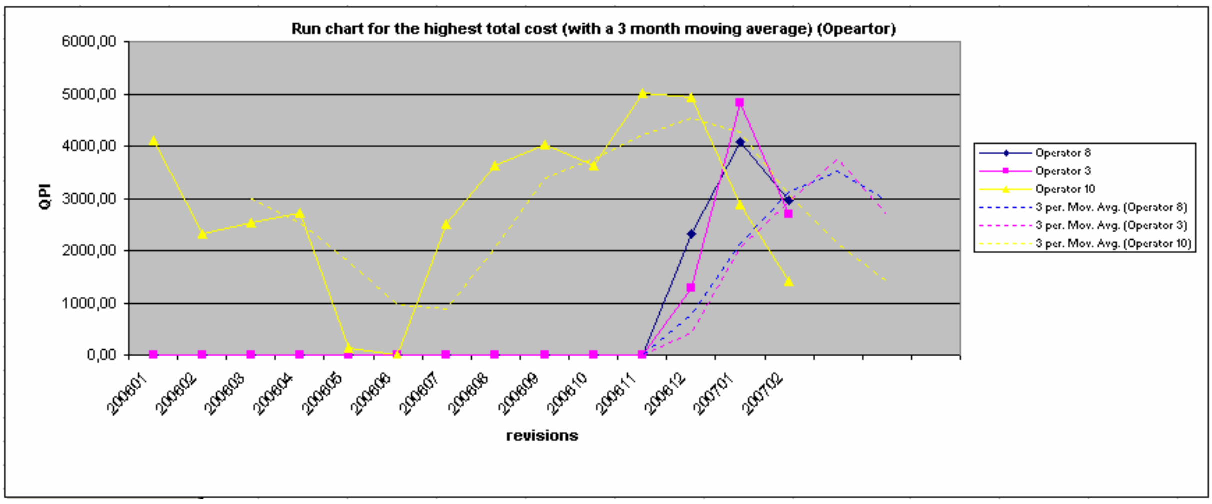


Figure 18 - Chart 3 Highest total cost and its 3 month moving average

Chart 4 (see figure 19) is the visual representation of the absolute difference. A high positive value would indicate poor quality and value close to zero would indicate a stable quality. Chart 4 to 6 has got the 3 month moving average plotted to facilitate the analysis.

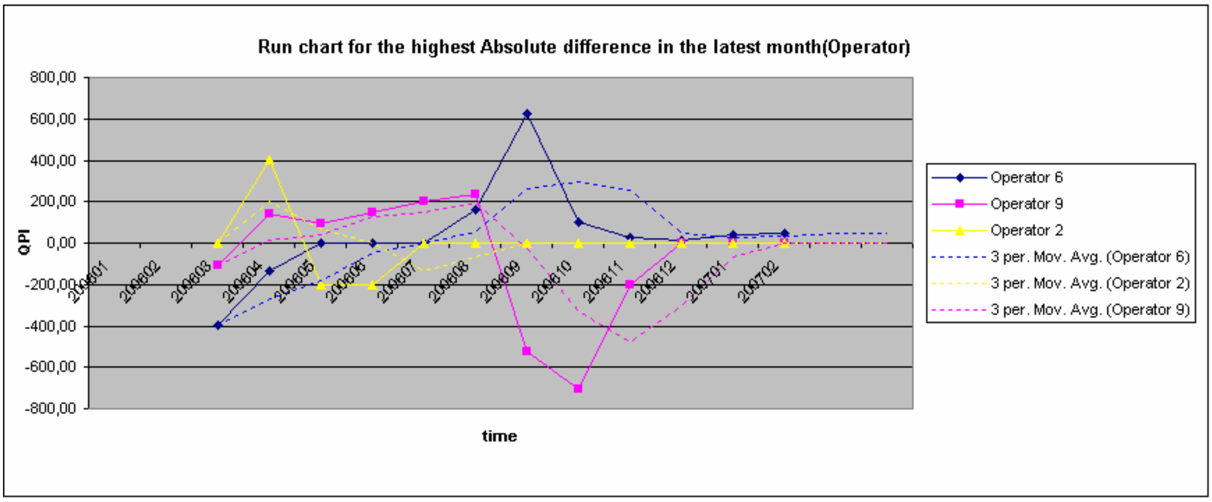


Figure 19 - Chart 4 Highest absolute difference

Chart 5 (see figure 20) contains information about highest relative difference. A high value would indicate that the value for the latest month is relatively high compared to the 3 month moving average. All revisions in the chart are showing signs of a troubled past but are now recouping due to the counter measures that have been deployed. Charts 4 to 5 indicate that the quality of the 10 operators is good or at least that they are showing signs of departure from their negative trend.

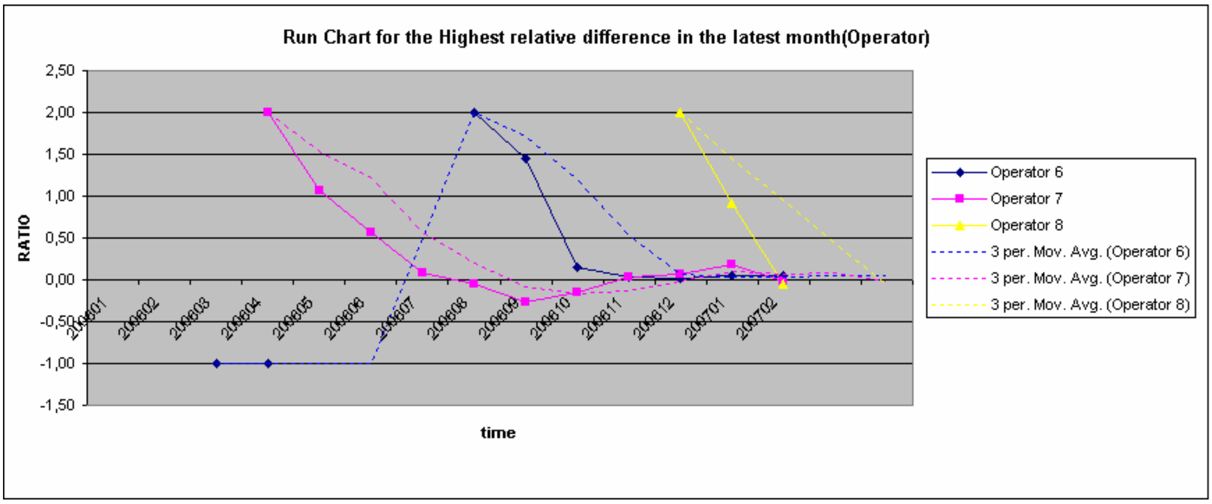


Figure 20 - Chart 5 Highest relative difference

Chart 6 (see figure 21) uses a longer average period for comparison. Even though the values are falling, 2 out 3 still have a magnitude bigger than zero which means that they are doing worse than they did 6 months ago. The different charts should be used in parallel with each other, but also as complements to the written information in the calculation tables. The different charts show different aspects and if only one is used as a source, the analyzer might miss some vital information.

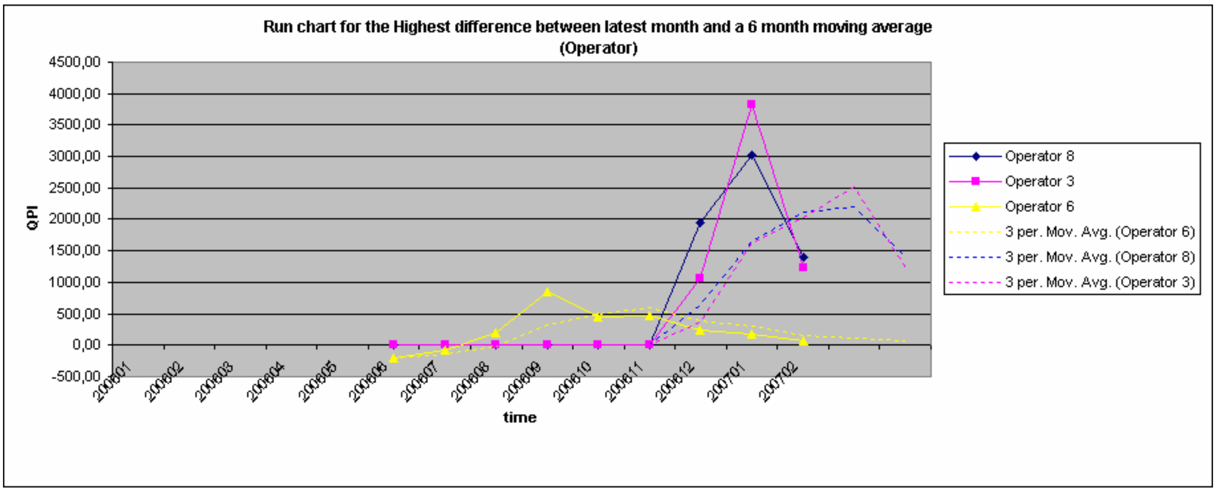


Figure 21 - Chart 6 The difference between latest month and a 6 month SMA

6.2.6 Could the Argus be applied to solve the problem?

Argus will be compared with the MTBA report that was the result after manually analyzing 6 revisions. The validity of the model could by this technique be measured from a MTBA point-of-view. 5 of these revisions can be seen in the following picture, 1 was removed since it didn't contain any data for the particular months.

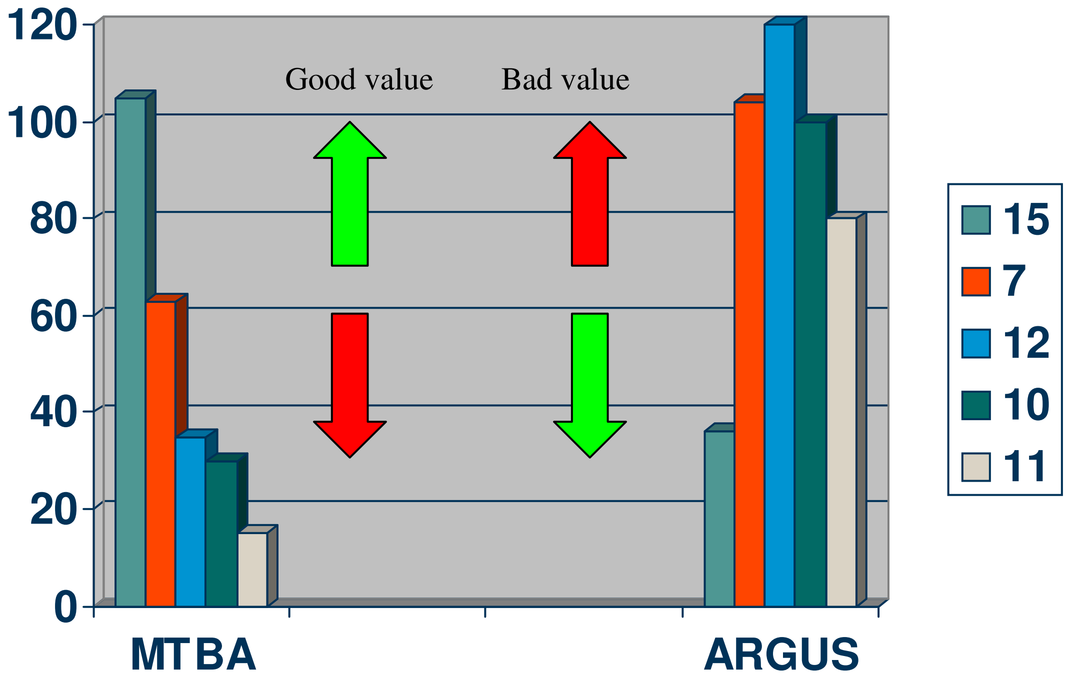


Figure 22 - Argus compared to MTBA

The limit in a MTBA report that a revision must be blow in order to be labeled as “bad” is called the robust level and the exact value of this limit can not be disclosed due to security reasons. The QPI values, in figure 22, of the Argus model has been adjusted to the same level as the MTBA model, so that a visual comparison can be made. The exact level that a revision must be above before it is labeled as “bad” depends solely on the values that are present in QPI categories. The QPI needs to be fine tuned before an exact value of “bad” quality can be determined and at the moment, the order is more important than the exact value. Revision 10 and 11 scores bad in both models, the difference is the order. 7 and 12 are placed slightly different in Argus than in MTBA. A perfect resemblance would have resulted in a mirror image of the MTBA in the Argus section. That would not have been an optimum finding since Argus is supposed to be better than the MTBA. If MTBA would have been perfect, then Argus would have been made as an automatic replica of MTBA model. The resemblance in the findings is noticeable and the difference is due to the values in the QPI and because Argus counts the number of alarming TGs, instead of merely looks at the number of fault codes that are above a maximum limit.

The authors believe that Argus can give an accurate description of the quality situation, solve the problem and help the analyzer perform his duties in a less time consuming way. The MTBA model can be said to solve the problem but, as the authors stated in section 4.1.4, contain some drawbacks. The MTBA model’s drawbacks made the authors of this text create Argus and its validity could be further increased if the QPI were additionally fine tuned. The alteration of the values in the QPI is a process that will continue for a long time and the QPI values might require some major modifications if the prerequisites are altered in a fundamental way. The weighting function (QPI) could in the hand of an experienced analyzer be tuned to capture the subtle nuances and help locate to problematic areas in a more precise way then before.

By giving an extremely annoying and damaging fault code, such as Reset SW Fault, a high QPI value would then highlight the revisions were this fault is frequent. Argus, like the Watchdog, does its calculations on the number of alarming TGs and this enables the model to focus on the more vital aspects that are overlooked when simply looking at the number of alarms that are above the maximum limit. The calculations and their data tables together with the charts are vital tools in finding and presenting the essential information in a good way.

6.2.7 The basic process for Argus in the context of the LCCA model

The following section contains a description of Argus from a LCCA point-of-view.

<u>Process 1: Problem definition:</u>

- What is the scope of SW or HW revisions that will be detected?
- How many input files or result files will be used to do the analysis?
- The definition of the time frame; weekly of monthly?
- How many categories will be considered?
- How to add the consideration of quality value for each fault code together with "effectiveness" of whole revision?

<u>Process 2: Cost elements definition</u>

Argus model focuses only on the vital part of the quality points or cost items, which will influence the cost of different categories. Therefore this is one of the major differences between LCC analysis and Argus model.

The cost breakdown structure can be used in Argus model to conduct the analysis. For the "life cycle phase", the time period setting in Argus model is 3 years from January 2006 to December 2008 and it can monitor the whole life cycle for different SW and HW revisions. Three "cost categories" or "quality categories" will be considered and they are Operator QPI, Ericsson QPI is and Subjective QPI. In the future, other QPI categories or sub-categories can be added in the model.

For "product/work breakdown structure"; Ericsson QPI contains three major parts in quality value which are repair, claims and HW. Operator QPI includes three factors which are dropped calls, missed handovers and site visits.

The predefined values in QPI can be considered as the major characteristic for the Argus model. The QPI is a big step forward and powerful tool which is not present in the MTBA model. The different impacts from all fault codes will form the final result and the result will therefore be more accurate and scientific.

<u>Process 3: System modeling</u>

In order to find the important relationships among a large amount of input data, parameters and cost categories, a model, with comprehensive functions, has been constructed. Argus (and Watchdog) is based on Excel Visual basic programming and it pinpoint the major contributors to poor quality in a large number of input files.

<u>Process 4: Data collection</u>

Argus uses actual data which are base data files and result files generated from RBS ISP Tool. The QPI uses a kind of estimation data which is coming form the analyzer's experience and it needs to be fine tuned several times before it reaches an optimum.

Process 5: Cost profile development
In the Argus model, the cost profile of each category has been done with the 3 month or 6 month moving average as comparison, which can be considered as a reference point.

Process 6: Evaluation
The result generated from Argus model, can be compared and evaluated with the MTBA model or discussed by analyzers.

Process 7: Optimization
In the Argus model, the optimization refers to finding the revisions which has the biggest influence within each category. One function which is called "QPI list setting" is added in Argus model, which facilitates the detection of the problematic areas. The QPI can be tuned to detect the veracity of the whole model.

The LCC is more detailed than Argus and therefore some aspects of LCC analysis can be added to Argus, which would make it more accurate and flexible.

6.3 Watchdog

6.3.1 General information, purpose and description

This section will contain information regarding our second model called the watchdog. This model was actually constructed as an integrated part of Argus but was removed when it became apparent that both a high- and a low level analysis were too complicated for the analyzer to conduct at the same time. It could despite this be fruitful to let both models analyze the same input data. The chapter will start with a general description of the model and later the vital parts of the structure will be presented.

More work has been done on Watchdog than on Argus. One reason for this is the problems that were encountered when working with finding the correct values for the QPI. The purpose of the watchdog is to look at the number and values of fault codes in the input files and react to an increase compared to a limit or an average. Watchdog performs a low level analysis and this means that it solely looks at individual fault codes. The input files can contain information regarding different SW-revisions, HW-revisions, OSS: s, Operators or Cabinets. These can be analyzed at the same time, but it would be like comparing apples and pears. The limit the model works with is the maximum limit, which is preset in by the RBS ISP Tool. If the average limit would have been chosen, more irrelevant fault codes would have been chosen and this would have flooded the analyser with information. A fault code that is above average could be an early warning sign that something is wrong with the quality, but it can also be normal fluctuations around the average limits. The basic structure of the Watchdog can be explained with the following flow chart.

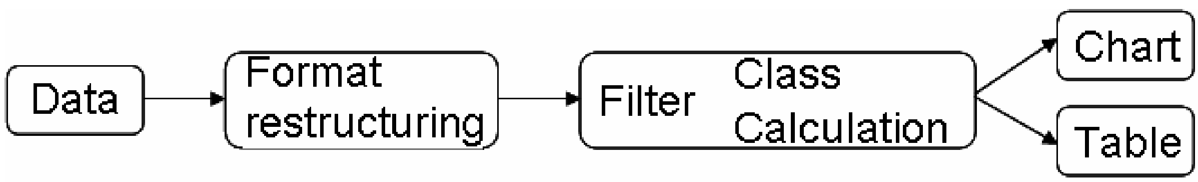


Figure 23 - Flow chart of the Watchdog

The data in figure 23 is the input data and it comes from the RBS ISP Tool. This data needs to be restructured by the Watchdog before it can find the fault codes that are responsible for poor quality. The update part of the model takes care of the restructuring, which must takes place since the input data comes in different shapes and needs to be converted into a standardized format. The analyze part of the model is the one that finds the essential information and it is done by a filter, classes and calculations. The presenting part of the model is responsible for making sure that the analyzer can perform further analysis and benefit from the Watchdogs findings. The presentation is done in charts and calculation tables. The general structure and control desktop can be seen on the next page.

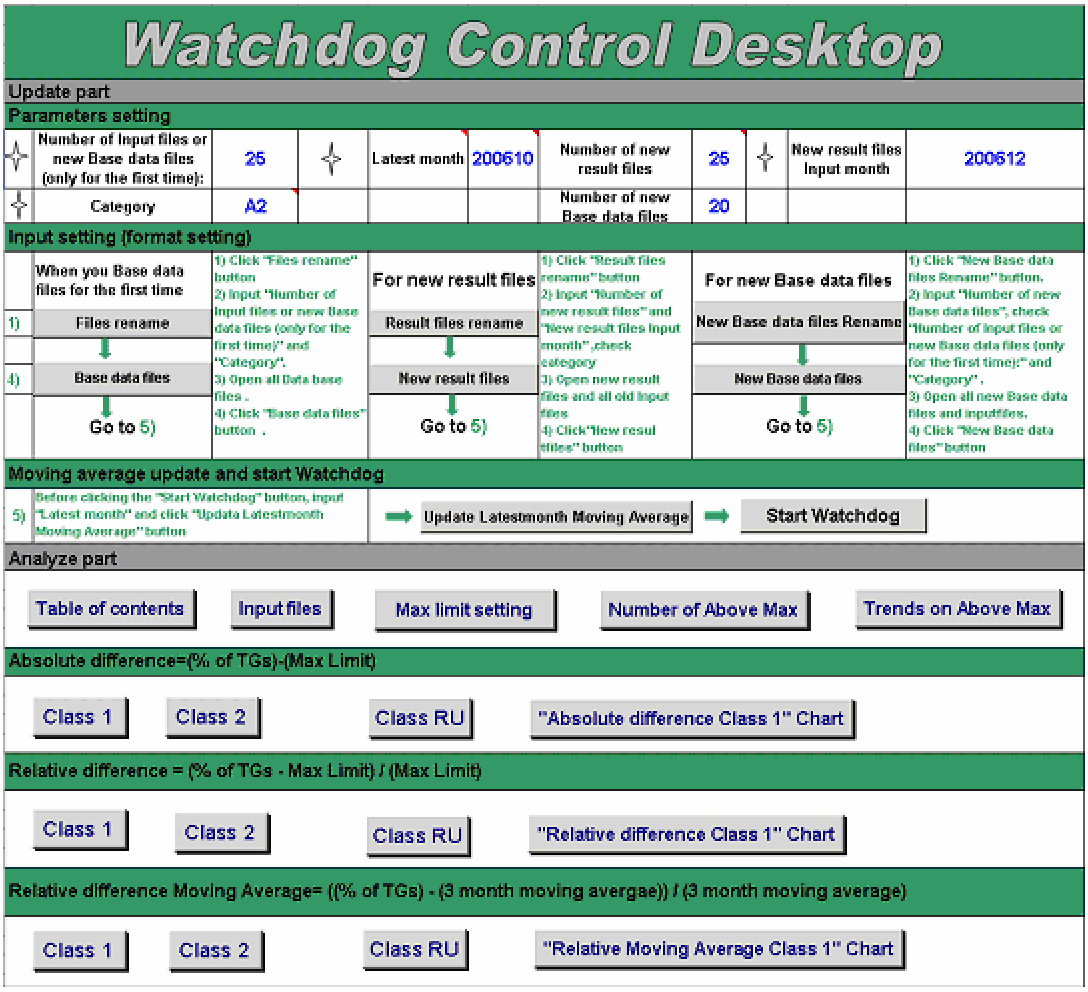


Figure 24 - Watchdog control desktop

The purpose of the control desktop in figure 24 is to facilitate the use of the model and make sure that the analyzer can take full advantage of the model in a fast manner.

6.3.2 Elements of "the analyze part" of Watchdog

The analyze part (everything below the grey line in the middle of figure 25) will be presented in the following section. "Max limit setting" is the filter function which is primarily used when the analyzer wants to examine how different maximum limits affects the analysis done by the Watchdog. This function is called the filtering function since the analyzer can filter out the unimportant information and this function can be considered to be the heart of Watchdog. If the limits in the filter function are wrong then the analysis will be misleading. The default values used by the RBS ISP Tool are derived from actual data regarding the RBS: s and this would secure a high probability of finding the correct revisions. The function called “Max limit setting” or the filter function can be seen in figure 25.

Control desktop | Table of contents | MAX LIMIT update | Reset MAX LIMIT to default value | Start Watchdog

FAULTCODE	FAULTTEXT		MAX LIMIT	AVERAGE LIMIT	Change	Default value
SO CF EC1:2	LMT (BTS Locally Disconnected)		1	0,1		1
SO CF EC1:4	L/R SWI (BTS In Local Mode)		5	1,2	Lower	8
SO CF EC1:5	L/R TI (Local to Remote while Link Lost)		0,5	0,2		0,5
SO CF EC1:6		0	0,1	0,1		0,1
SO CF EC1:7		0	0,1	0,1		0,1
SO CF EC2:9	RBS DOOR (RBS cabinet door open)		100	16,4	Higher	38,2
SO CF EC2:10	Mains Fail (External power source fail)		5	11,6		5
SO CF EC2:11	ALNA/TMA Fault		5	1,5		5

Figure 25 - Max limit setting with altered data

If the analyzer wants to exclude one fault code from the analysis, he can simply change one of the values under *max limit* to 100%. This has been done in the figure 26 for the fault code for *RBS cabinet door open*. If the fault codes that truly are unimportant (differs from category to category) could be found and taken away, the charts in analysis could be made easier to read and analyze. The chart, in “trends on above max”, would then look more like a straight line with a specific angle compared to the roller coaster ride it usually looks like if all fault codes are present in the charts. The *max limit* for *BTS in local mode* has been lowered to 5 % instead of 8 %. This would place this fault code higher up in the calculation analysis and would then be easier to find. The number of revisions which would have been in local mode more than this 5% maximum limit would increase and the importance of this fault code has been increased by this alteration.

In figure 26 the “Number of Above Max” can be seen. The analyzer can find information regarding the number of fault codes that were labelled as “above max”, for a specific revision during the month which was called latest month. A high number points to a suboptimum situation and the values are sorted in descending order.

Control Desktop | Table of contents

200702	Number of Above Max	3 month moving average	Absolute difference	Relative difference
Revision 3	34	34,00	0,00	0,00
Revision 8	25	24,00	1,00	0,04
Revision 5	18	16,67	1,33	0,08
Revision 1	15	8,67	6,33	0,73
Revision 4	10	5,00	5,00	1,00
Revision 7	8	5,33	2,67	0,50
Revision 6	4	9,00	-5,00	-0,56
Revision 2	2	1,00	1,00	1,00
Revision 9	1	0,50	0,50	1,00
Revision 10	1	0,00	1,00	#DIV/0!

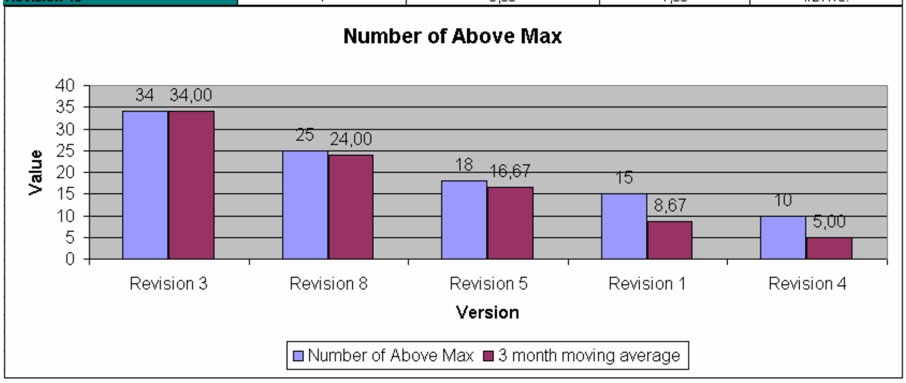
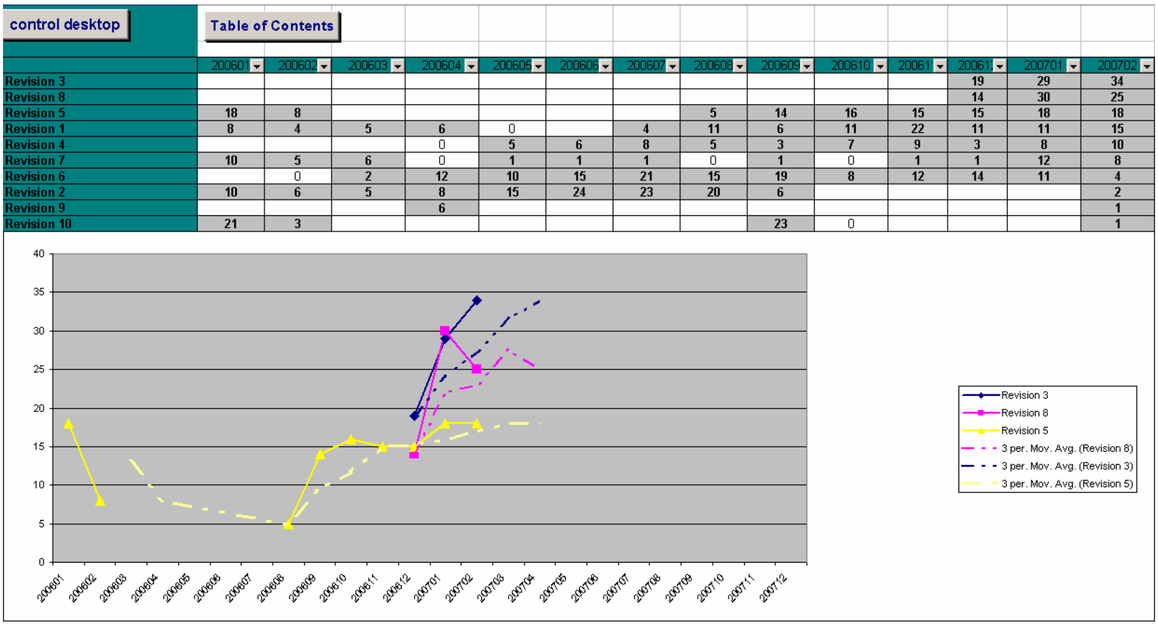


Figure 26 - 10 revisions are analyzed during the month 200702

The next function has similar data but also a historical information. The “trends on above max“ is used to show how the number of above a maximum limit has developed over time. This enables the analyzer to understand if a specific value is high compared to former months. The model finds the 3 revisions with highest number and plots them in a separate chart. The “trends on above max” and its chart can be seen in figure 27.



	200601	200602	200603	200604	200605	200606	200607	200608	200609	200610	20061	20061	200701	200702
Revision 3												19	29	34
Revision 8												14	30	25
Revision 5	18	8						5	14	16	15	15	18	18
Revision 1	8	4	5	6	0		4	11	6	11	22	11	11	15
Revision 4				0	5	6	8	5	3	7	9	3	8	10
Revision 7	10	5	6	0	1	1	1	0	1	0	1	1	12	8
Revision 6		0	2	12	10	15	21	15	19	8	12	14	11	4
Revision 2	10	6	5	8	15	24	23	20	6					2
Revision 9				6										1
Revision 10	21	3							23	0				1

Figure 27 - “Trends on above max” function with data from 10 revisions

The calculations that are used in the Watchdog to find the trouble areas are:

- The absolute difference is: *(Number of above max – max limit).*
- The relative difference is: *(Number of above max – max limit) / max limit.*
- Relative difference Moving average is: *(Number of above max – 3 month moving average) / 3 month moving average.*

This relative value is an increase or decrease in % from either a *max limit* point-of-view or a *3 month moving average* point-of-view and a value of 1 represent an increase of 100 %. The charts in the Watchdog could help the analyzer find the crucial data if the analysis is done on many revisions and it also gives a visual representation of the difference. The fault codes are separated into 3 calculation parts and further divided into 3 subclasses; class 1, class 2 and class RU. These classes exist in the RBS ISP Tool and are used to give different fault codes different priority. Class 1 are the most serious one and an example could be “SO CF I1A:12 DC Voltage out of range”. This means that the voltage within the cabinet has dropped to a specified level were the RBS shuts down. There is a similar class 2 fault SO CF I2A:18 DC Voltage out of range and that level is reached before the class 1 alarm is reported. Class RU (Replaceable Unit) alarms are connected to the unit that has been singled out as the cause of an alarm. One alarm can be caused by different RU: s, so when one of these sends an alarm, a class RU alarm is also send. Not every alarm have comparable alarm in another class, one example is the alarm “Traffic Lost Uplink”. When traffic is lost there is no need for a class 2 alarm due to the severity of that problem. A separation of the classes enables the analyzer to focus on the more important alarms and still be able to check class 2 and class RU if he thinks that this would help the analysis.

A graphical representation of the absolute difference (class 1) has been plotted in the model in a separate chart. Only class 1 alarms have a chart, since the analyzer will pay most attention to these alarms. The chart has only got the basic information to facilitate a quick read of the current state.

6.3.3 Could the Watchdog be applied to solve the problem?

The model named Watchdog reacts to changes that happen on an individual fault code level. The changes are calculated from historical data regarding the number of above a maximum limit or an increase compared to a specific value (maximum limit or moving average). The lower level analysis will not pinpoint entire revisions or cabinet, but merely the fault codes that are behaving in a negative way. This specific fault code could very well be a part of a revision that otherwise would be deemed to function properly by a manual analysis or an analysis done by Argus. The finding of an individual fault code among several revisions is an important task, since finding the problematic areas is a part of the problem formulation. The watchdog functions properly without any weighting function and without any tempering with the filter function. This means that the model could from day one start finding the single most fault code among an entire population, but the finding of fault codes is improved by the filtering function. This function could be fine tuned to filter out the fault codes that have no actual affect on the performance or are considered to be less important due to a number of reasons. One such reason could be that the particular fault code have already by addressed and remedied but the affect of the actions wont be noticeable until several weeks have gone by. The filter function requires a lot of background knowledge but it increases the reliability. The calculations are responsible for finding the important fault codes and then sort them in descending order so that the fault code with the highest difference is placed in top of calculation table. The objective has never been finding one single complicated mathematical formula that covers all eventual possibilities. The creators of the models followed the assumption that simple is better and they chose 3 mathematical formulas that covers different areas. They should be used in parallel to make sure that several aspects are considered before further analysis is initiated. If not all three calculations are considered an important fault codes could be overlooked.

Absolute difference:
Absolute difference is one way of simply looking at the magnitude of the difference without judging it compared to the maximum limit or the moving average. It is more likely that fault codes with a high maximum limit will be presented by this calculation, since they are more prone to oscillate with a higher magnitude, in absolute numbers, around it average limit. These fault codes could also be of interest so that is why this calculation is present in the model.

Relative difference:
A slow growing trend could be disastrous if it is not spotted and analyzed in time. A sudden increase could also be an indicator that something is wrong and requires further investigation. If the value for the latest month is high, but low compared to former months, then this would indicate a positive trend in quality and that something probably have been done to mend the problem. A third scenario is an oscillating pattern with repeating peaks and valleys. A high value could be a part of natural pattern that repeats it self i.e. due to external weather conditions.

Moving average:
When new revisions are added it can be deceptive to merely focus on data from the latest month. No comparison to former months will be made and sudden increase compared to an average value will pass through the filter if the value is less than the maximum limit, if the moving average is not used. Even if the value is above the maximum limit, it will be placed low in the calculation table if it is only marginally higher than the maximum limit. The models way of solving this problem is to calculate a moving average for the past months and compare the latest month data with that number.

The manual work merely looks at the number of fault codes that were above the maximum limit and the historical data was often ignored. One way of using the existing technique, but at the same time improve it has been the function called "Trends on above max". This function contains historical data regarding the number of above a maximum limit, so that a comparison between the latest data and the historical data can be made. This comparison will be made by the analyzer after the Watchdog has located the revisions with the highest number of fault codes that are above a maximum limit. A comparison with the historical data will place the number of above a maximum limit in relation with former data, and this could further enhance the need for deeper analysis if the analyzer finds the historical data indicating a deteriorated quality trend.

The presentation format in the Watchdog is calculation tables, bar and run charts. The calculation tables will always contain the complete set of data and can be a great source of information, since it enables the analyzer to compare the fault code with other fault codes in the same class. The bar and run charts are there to enable the analyzer to see a short summary of the most vital parts. The bar charts are a visual representation of the calculation tables and the run charts can be analyzed by using the SPC-rules in-order to find shifts and trends. The number of fault codes and revisions in the charts are as few as possible so that an efficient read out can be made.

The MTBA report states that fault code 10 (revision 0) and fault code 11 (revision 1) are the most essential to focus on to improve quality. These fault codes are class 1 and they severely affect air traffic and they have been found be the manual model to have risen in numbers during the latest months. The complete MTBA report with the actual names will not be presented due to security reasons. All 3 calculations have placed the fault codes 10 and 11 in the top 6. Relative difference moving average placed the fault code 11 revision 1 in the top spot. The other combination 10 & 1 and 11 & 0 can also be found numerous times in the top 6 in all calculation tables. Other fault codes, such as number 5, have been found by the Watchdog and have been deemed to be interesting for further analysis by the people responsible for the MTBA report. They might, according to them selves, have overlooked these fault codes during the manual analysis.

The Watchdog needs further evaluation but initial trials have been promising and have revealed the same sore spots as the previous manual model and additional interesting information has also been disclosed. The importance of the additional findings can be estimated by veteran analyzers and they claim that the findings look promising.

7. Conclusions

The solutions that the authors have contributed with are placed after each problem and purpose that they stated in the beginning of the text:

Problem: To be able to find the items that negatively affect quality the models will have to search for and find the vital data within a huge population. The problem of finding the essential information can be described as finding a needle in a haystack.

Solution: Models were constructed to do their calculations based on the number of alarming TGs, since only a small number of RBS:s could be responsible for a big portion of the fault codes that are above a maximum limit. This phenomenon is offsetting the current MTBA analysis and by altering the search parameters, the needle doesn't become hidden by the hay.

Problem: When the essential information has been located among thousands of reports, the problem of presenting the information arises. The reports has to be manipulated to show only the most important information in such a way that the analyzer doesn't get confused or overwhelmed by the sheer volume of data.

Solution: The presentation format is based on the notion that simple is better and that a human being easily becomes overwhelmed with information. The charts in A&W are easy to read and doesn't contain too much information. They can be analyzed to detect trends and shifts by using historical data. If the analyzer needs more detailed information, he can simply use the calculation tables where all data is present.

Purpose: The purpose with the model is to pinpoint the fault codes and the revisions that are the major contributors to deteriorated quality. The models are supposed to assist the analyzers by performing the sometimes tedious work of going through lots of paper reports and lead the analyzer in the correct direction.

Solution: By constructing two models that automatically can search thousands of papers, the analyzer can focus his attention and knowledge on the fault codes and revisions that have been chosen for further analysis. The models use a weighting function and a filter function to detect the spots that would, when focused on, improve quality in a grand manner. Each fault code can be weighted against other fault codes or filtered, this would increase the validity since only the most important ones are left after the models has performed its functions. The result is presented in tables and charts that states which fault code or revision the analyzer should focus on to remedy the major contributors to deteriorated quality.

The findings have been discussed in the light of an existing manual procedure (MTBA) and other methods used in quality controlling, such as SPC, LCCA and Six Sigma. They have been used in different ways:

- The MTBA has been presented and one of its reports has been used to establish the validity of Argus and Watchdog.
- SPC was examined to see if it could be used to solve the problem, but it could not mainly because of troubles with finding an appropriate control limit.
- LCCA was used to analyze Argus, since they both can be said to measure costs/quality points.
- Six Sigma was used as inspiration since it is more of a methodology than a model.

The advantages and disadvantages of Argus and Watchdog are:
- Handles large number of input files at the same time.
- Easy to find the major contributor in different categories.
- Useful charts.
- Easy to update.
- It is easy to add new functions in the future investigation.
- Separated coding whcih makes it easy to develop further.
- Good tool to detect trends and shifts.

Disadvantages with A&W are:
- Only the report generated form RBS ISP tool can be used as input in the models.

With all this in mind, the authors of this text and creators of the Argus and Watchdog strongly believe that A&W could solve the problems and help the Operation & Maintenance department in their quest to improve quality.

8. Future research areas

The models will be used as a guide for the developers of RBS ISP Tool. The authors have found two possible ways of changing the tool in the future. Either the output of RBS ISP Tool changes so that an external model like Argus or Watchdog can work directly with the result file, or the two models can be implemented in RBS ISP Tool. The output from that updated RBS ISP Tool could then, if the coders want it, look like the output from the models. The latter version is probably more likely. Even if the RBS ISP Tool coders decide to rewrite everything from scratch, they can still find useful inspiration in the code and in the models design.

It is important to follow up on the pilot project with T-mobile and see what conclusions can be drawn from that project and see what these can do for Argus. The weakest and strongest sides can be used to further enhance the performance of Argus. A follow up on the weekly meetings and the Watchdog would also be fruitful. Potential improvements will be seen rather fast but whether it actually will save money for Ericsson might take some time to establish.

The RBS ISP Tool could possibly be installed in all RBS: s and send randomly chosen data via mail to the analyzer or input this data directly into the models. This would give a better view of the overall population and the results from A&W would have a higher validity. Other improvements could be:

- Add data from ECHO, Tracy and MTBF statistics. [17],[66],[67]
- Other steering and problem solving methods like Pareto analysis, Ishikawa (fishbone), failure mode and effects analysis could be used as a base for comparison or as a model for future improvements.[68]

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