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Integrating Q&R in the production department of Company X Place y

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Management Summary

Company X is an independent and certified test house and analysis lab for optic- and microelectronics. Company X's portfolio consists of several different parts in the test cycle. The engineering, test and programming are part of the activities, as well as qualification and failure analysis. Company X can also apply their specialism in the whole supply chain, assisting and supporting their customers with a supply chain service.

Company X has several facilities in Germany. The main production or testing department is located in Place y in Bavaria, Germany. Company X GmbH is the result of a merger between Microtec GmbH in Place S and Rood Testhouse International N.V. in Place Z and Place y. As a follow-up on this merger and to obtain higher productivity in the production department, the raw production, i.e., the testing, has been moved from Place S to the facility in Place y.

Although the companies merged in 2008, the two different production facilities were never combined until the process was started in early 2012. The main production areas in Place y are Qualification & Reliability and Test Engineering & Programming. The approaches to these production areas were different, most of the production was done differently and the perspective on the business was different, although both production areas are part of the same company.

During the internship at Company X, we saw this discrepancy. There were several indicators that the parties were working next to each other and not so much with each other. The best example for this was the way the planning of the Q&R and TE & PSS departments differed from each other. In Q&R, the process description is written in excel, while TE & PSS used an ERP system. This problem was the main issue we had to deal with at Company X, thus our main goal was to **provide Company X with insight in the current production and planning process in TE and Q&R.**

This led to our research question, as we believe that combining these two practices into one smooth flow, the production inefficiencies could be turned into winners for Company X. The main research question is the following:

"In what way, given the current available machinery, employee database and culture at Company X, can the department of Qualification & Reliability be integrated in the production floor?"

This report is an analytical view of the company production process with a qualitative nature. The research should give the management of Company X insight in the difficulties of a technological environment and culture while striving for change. This research is based on the experiences on the production floor and this report adds value through its literary perspective. The research starts by providing insight in the production departments of Qualification & Reliability and Test Engineering & Programming. Elaborating on the differences and the similarities between these two departments, an analysis is made on all levels, machinery, employees and planning and scheduling. After this analysis, we will discuss the literature required to provide Company X with tools to improve the integration. Finally, conclusions and recommendations were made regarding the best practices and solutions for semiconductor companies.

Using the process described above, we have tried to identify the problem areas of Company X and to deliver an insight in the company in order to help Company X with the integration of Qualification and Reliability with the rest of the company. There was an obvious 'us versus them' culture inside the

company, driving a wedge in the communication and the corporate identity and corporate goals. The merger from 2008 had not been processed correctly, and management made top down decisions. Although this is not necessarily a bad thing, the gatekeepers weren't involved at all, reducing the effectiveness of the decisions that were made.

The physical border between the production departments has already been removed by the merger and the transportation of the Q&R department to Place y. The cultural integration has to catch up. An example of this is the lunch room, in which the different departments never join each other, but only lunch with their own department. The similarities between the departments are enough to start pooling employees and exchange information. This can be done on every level with increasing difficulty, from the operators to the engineers. The pooling of operators from the departments is, with minor training, currently possible and a viable option.

A means to an end in the corporate culture and identity for Company X is the implementation of a new ERP system. This system provides a window of opportunity to reinvent the business process of all the departments, especially Q&R. Reinventing the business process and guiding the departments more towards the same identity and corporate beliefs are the factors that will help Company X survive in the killing market they are in.

Glossary

List of abbreviations

TE	–	Test Engineering
Q&R	–	Qualification and Reliability
PSS	–	Programming
IC	–	Integrated Circuits
BI	–	Burn In
SCM	–	Supply Chain Management
FA	–	Failure Analysis
SIA	–	Semiconductor Industry Association
ESD	–	Electro Static Discharge
PPS	–	Production Planning System
ERP	–	Enterprise Resource Planning

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Preface

In front of your lies the bachelor report of Robert Zwart and Jeroen Enthoven, the product of an internship we performed at Company X in Place y, Germany as a completion of the Bachelor Industrial Engineering & Management at the University of Twente.

In May 2012 we started out at Company X in Place y to study the production floor of Company X GmbH. We were placed in the efficiency team, to have a direct information line with the supervisor. Here we met our fellow team members, who showed us around for the most part and gave us a tour of the company. We had a nice time working at Company X in Place y. The internship helped us to get a better understanding of the optic- and microelectronic sector. The highly technical testing was very interesting and was a great possibility to see how our day to day electronics are produced and tested. Our internship in Germany was also a nice opportunity to learn more about the business and culture in the neighbouring country. A minor negative aspect of the internship was the European football championship during our stay, in which the Netherlands decisively lost to Germany.

We would like to thank all employees who helped us at Company X. From the University of Twente we want to thank dr. Peter Schuur for his constructive feedback and pleasant meetings on the research.

Last but not least, we would like to thank our families and friends. Their support helped us through rough patches in the research and they always stayed positive.

Robert Zwart
Jeroen Enthoven

August 2013

1. Introduction

This report is the result of a two-month internship at Company X in Place y, Germany. This research is the final paper to complete the Bachelor study Industrial Engineering and Management at the University of Twente. The research includes aspects of the contents studied in the curriculum of the Bachelor courses including process flows and insights on the internal organization as well as ERP software and database knowledge. This first chapter is meant to introduce the corporation that is Company X and a brief description of the activities that take place in Company X Place y.

Company X N.V. is an independent company specialized in the certified testing and laboratory research of optic- and microelectronic devices. These optic- and microelectronic devices can be found in almost every part of our lives. Think about the airbag in your car, the chips in your phone or the technology going into satellites. The chips or Integrated Circuits (IC) need to be tested to reduce the failure rate when performing under different circumstances. The tests try to replicate durability wear, long exposures to warmth or cold and changes in temperatures. Being a test house, Company X N.V. facilitates these tests for their customers, making the need for a non-core process, such as testing the ICs, redundant for the customer.

Company X Place y is the largest facility of Company X N.V. The production for the departments Qualification and Reliability / Burn-In (Q&R / BI), Test Engineering (TE) and Programming (PSS) takes place here. Other departments represented in the Place y facility are a part of the Sales, Internal Sales, Planning, Expedition, Supply Chain Management, HR and Consulting. These are mostly configured to support the testing process on the production floor, to help customers in fulfilling their needs or to control the internal process.

The current holding of Company X was formed in 2008. During the years 2008 to 2011 the status quo of the company hasn't changed. The two merging companies (Rood Testhouse International N.V. and microtec, testlab for opto+microelectronics) had their own planning, their own schedule and worked as similar independent companies, which was a cause for the internal competition and a 'us versus them' culture that followed. During 2011 this setup, that enabled the two facilities to work independently, was to be eliminated. The purpose of integrating the production facilities of Company X was to excel in Place y in Quality & Reliability and Test Engineering and the production facility in Place S in Failure Analysis. Currently, TE has been transferred completely from Place S to Place y, while certain Q&R processes are still performed in Place S.

In order to achieve complete synergy among the plants in Place S and Place y, and within the two plants themselves, a new Enterprise Resource Planning system was launched in October 2012, called Apollo. The previous ERP system, Oxaion had proven to be outdated and was not fully integrated within the entire organization, and is therefore susceptive to change. However, replacing the old ERP system with the new one will cause significant changes in day-to-day activities, and thus this report is partly focused on maintaining and regaining overview. The Place y facility is the focal point of this research, due to the production departments of Q&R and TE that are situated in Place y.

2. Research Design

In this chapter, we will thoroughly describe the structure of the entire research, as well as the complementary report. We will discuss why we chose for our specific scope and explain the research questions as well as our research method.

2.1 Purpose of research

The purpose of this research is to **provide Company X with insight in the current production and planning process as well as the use of capital, both through labour force and machinery, in the areas of Test and Qualification & Reliability**. Company X is experiencing a decline in turnover over the last year and in times of uncertainty it is highly beneficial to gain complete insight in the organization in order to reassess the strong and weak points.

During the first week of our stay in Germany, after having talked with various employees and the board, discrepancies between how the organization should function and actually functions surfaced. The amount of Burn-In orders declined drastically over the past three years due to a diminishing amount of large customers. There has been a shift from customer to competitor, since the larger customers started in-house testing. The division of Qualification & Reliability uses almost ‘at random’ planning, making the planning of personnel and machinery rather chaotic. Company X’s liquidity also decreased to a point where “kurzarbeit”, short time working for a reduced salary, is a necessity.

During the course of this thesis, all of the problems described above will be (re-)assessed in order to provide a practical solution that improves the production process in the area of Qualification & Reliability. This pragmatic solution will be based on the merits of the literature and the theoretical perspective.

2.2 Scope

Due to the constraints on time and resources, it is preferable to narrow the research to a specific part of Company X Place y. As shown in Appendix B, the problem relations, areas worth investigating are of financial, sales or logistic origin. Company X has taken some form of action already in some of these areas, e.g. ‘kurzarbeit’ to help with the low solvency. In other areas, the direct influence of Company X is insufficient to make a difference. Therefore, the investigation should be prioritized accordingly. The research in this thesis focuses on the production process of the Qualification and Reliability / Burn-In department (Q&R). Although there is a certain overlap between the Q&R department and the production in the Test department, these are different processes and should be treated as such. The issues in the financial region, the problems with the liquidity, are already under the attention of the management and therefore excluded from the research. The change in customer orders at sales is market driven and is less controllable than the internal processes. The arguments for using this scope are as follows:

- The Qualification & Reliability department works mostly project based and should therefore be more flexible in assigning and using employees and machinery.
- The Q&R department is recognized, by higher management, as one of the fields where profit margins could be higher.
- There is no clear insight in the overview of every current order in the Q&R department and the status of those orders. Before such an overview can be made, several employees have to be consulted, whilst such an overview should be available to everyone at any given time.

2.3 Problem definition

In the previous paragraphs, we defined the goal and purpose of the research, as well as the scope that we are going to use to achieve the goal. In this segment the main question and sub questions of this research will be discussed. As stated above, the Q&R division uses a random planning, disallowing a clear, easy-to-access survey as to which machine or what worker is used for what customer order. Also, certain proceedings of an employee from the Test division are similar to those of the Q&R division; therefore it may be beneficial to use these persons in both divisions via retraining. Since a reassessment of the use of capital in Q&R is of importance, the sub questions are:

1. "What is the current situation in Q&R, looking at customer orders, usage of equipment and personnel?"
2. "What needs to be done before personnel can be used for both Test and Q&R?"
3. "Which problems commonly arise when implementing a new ERP system and which of these problems should be taken into consideration by Company X?

By answering the first sub question, some transparency into Q&R can be created and thus enable a quick view as to what orders, machinery and personnel are available. This first question is of importance, seeing as such overview is not easy to access at this point. After this question, question two is identified as the basis to allow an exchange between employees from Q&R and TE. Downscaling in workforce may be a possibility while considering the safety regulations. Question three is a literature study to gain knowledge about a possible solution to further allow the exchange of employees between departments. By enabling personnel to be able to work for both Test and Q&R, labour restrictions can be lowered. As of this point there are two smaller groups that work solely for either Test or Q&R. With one larger group meeting customer demands may be easier.

The usage of machinery includes another uncertainty. As of this moment, it is unclear what the exact unit costs are. There have been many eventualities that caused more machine down-time than anticipated or more labour hours due to higher set-up times. There have been many discrepancies between pre-calculated costs and actual costs; making production runs less profitable, in terms of revenue versus production costs.

Since the start of June 2012, the short-term liquidity problem is being handled by decreasing labour costs. A large amount of workers are submitted to "kurzarbeit", meaning a temporary decrease of ten per cent of their workweek. Long-term research may lead to the conclusion that there is redundancy in work force.

The decline of customers due to in-house testing is a shift in the market in which Company X operates. Changes in the environment of an organization are difficult to control or adjust and lie outside of the scope of this research.

In this research the focus lies on the problems stated in the first paragraph of this section. Taking the three sub questions into account the following main research question comes to surface:

"In what way, given the current available machinery, employee database and culture at Company X, can the department of Qualification & Reliability be integrated in the production floor?"

If this question has been answered sufficiently, it is known where the main focus point should lie in order to improve the transparency of the production processes at Company X. If the production processes are more transparent and accessible to the workforce, a suitable planning can be made for Qualification & Reliability. That will be the first step towards the various problems that are occurring at Company X under the current situation.

2.4 Research Method

In order to obtain all the necessary information for the research, a clear research method is paramount. The scope of the research is known, Company X's divisions Test Engineering and Quality & Reliability will be studied. To obtain information regarding improvement within these divisions, it is important to know the current situation of these divisions. Therefore, we start our research with a feasibility study. We question several employees to comprehend their everyday experiences. However, in order to keep the research open minded and not too focused on one point of view, members of the Board and Margin Improvement Team are also asked for their opinions. Based on these findings, improvements in synergy between the production departments will become visible. This synergy will be the focus of the research.

Improvement may prove difficult to determine and may not be experienced as improvement at all. Therefore, expert opinions are derived from relevant scientific publications, as to acknowledge these areas and possibilities to improve them.

Since this research is done by two students, the findings are roughly divided over the two divisions, Test Engineering and Qualification & Reliability, all available in the same document.

3. Current Situation of Company X Place y

Company X has a rich history of mergers and expansions. In 1976, a company called xxxx established itself in Place Z, The Netherlands. At this point, the organization xxxx in Place y, Germany, had already been taken over by Philips Semiconductors. In 1982, xxxx was founded in Place S, Germany. These organizations merged, expanded and changed their name several times (Appendix A), but in 1991 two of these three companies came together. Xxxx from Place Z and xxxx from Place y merged. This was followed by a series of joint-ventures and mergers in the United Kingdom, Malaysia and Taiwan, but it was not until 2008 when xxxx and xxxx merged to form the current holding Company X. Nowadays Company X N.V. has a turnover of around 16.7 million Euros (2008) and consists of 162 employees. Company X N.V. is situated, as shown in figure 1, in Place Z (Netherlands), Place D (Germany), Place S (Germany) and Place y (Germany). As mentioned earlier, in Place Z the Board is located and in Place D a small sales department. Place S is responsible for Failure Analysis whereas the department in Place y performs Q&R, TE and PSS alongside several HRM-related tasks.

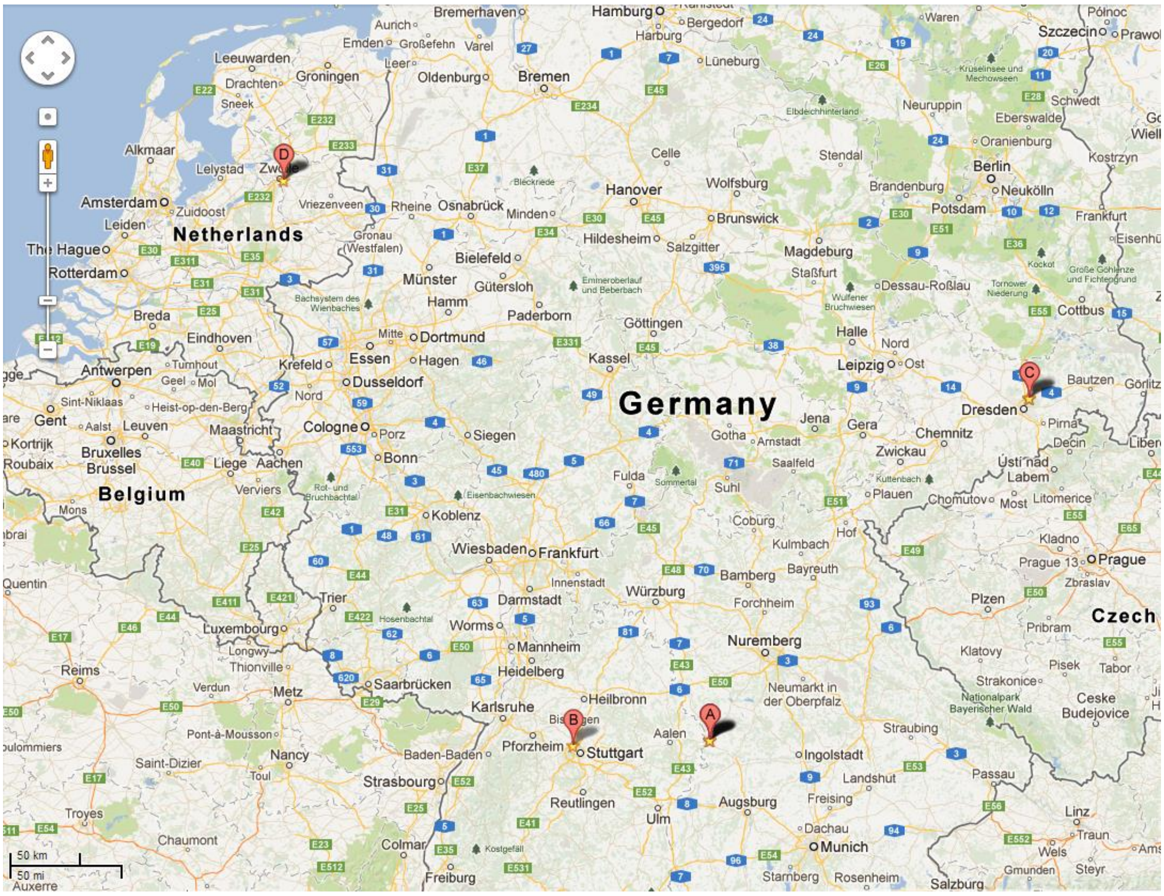

Figure 1: Facilities of Company X

3.1 Production flow

The main product Company X offers to its customers is the qualification, testing and analysis of semiconductors. Before a product is being tested or qualified, however, there are several processes a product has to undertake before being submitted to the correct division for actual testing and qualification. The order process commences with the customer that wants to place an order at Company X. The sales division will then specify to which division an order belongs. The specific division will then calculate, together with the technical sales division, whether the order is profitable or even producible and send a preposition back to the customer. If the customer agrees to the preposition, the production process can start.

After the pre-ordering phase, the order arrives at the planning of the specific division, and will then be planned in for production, based on estimations for production time and production dead line, and therefore priority. The specific processes regarding Test and Q&R will be described more thoroughly in chapters four and five.

After the order is planned into the schedule of one of the divisions, actual production takes place. If the production is flawless and matches the schedule, the finished goods are transported to the packaging division where the product is packaged airtight, after which it can be shipped to the customer itself, or a location of the customer's customer. However, the possibility is exists that complications arise. Unscheduled calibrations, machine breakdowns or unscheduled prioritized products often lead to a change of plans. In this case, the customer is notified with the expected delay and the reason of this delay.

Lastly, nowadays Company X aims to provide customers full supply-chain service. Basically the entire process described above is offered as one package as it is designed to relieve the customer of every step in the production process, from acquiring the required resources to produce the batch to delivering it to their customers. The exact point in the process as of which the customer wants to be relieved of duty is specified by the customer itself. A schematic display is seen in figure 2:

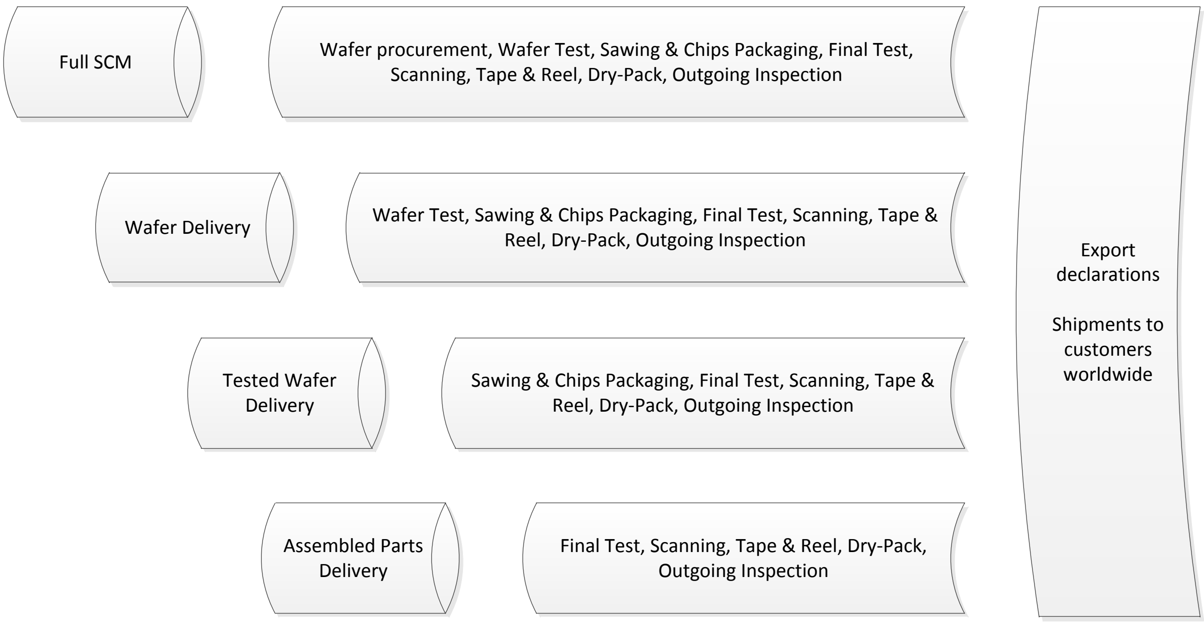

Figure 2: Supply Chain Services

3.2 Production departments

The production plant of Place y does not, as stated above, perform all possible services that Company X offers its customers. The Failure Analysis department remains in Place S. This service is provided to customers that have an unknown failure in their product. This can be a mechanical defect as well as a programming failure. The FA team will submit the product to various extensive tests that stretch out to microscopic level, in order to find the defect and repair it.

In Place y, the production area, or plant, is roughly divided into two divisions: the Test Engineering and Programming division, and the Qualifications & Reliability and Burn-In division. This is shown by the specific hierarchy in personnel within these divisions, as will be discussed in the next section. Also the layout of the production plant supports this organizational view, as it is clearly divided into these two divisions. The layout of the production area in Place y is shown in Appendix C.

The Test & Programming division submits the various chips and wafers to tests, and is able to program these chips to respond properly to specific situations. These chips are tested and programmed specifically to the needs of a customer and therefore different standards need to be matched every time. If a batch of chips is meant for the automobile industry, there are strict restrictions and regulations that require every single chip to function exactly how it is designed to function. A batch from the mobile phone industry, however, could be tested in a random order with the purpose to obtain a certain success ratio. A failing mobile phone chip can easily be replaced without hazardous situations.

Customers that ask for specific qualifications or standards are helped in the Qualification & Reliability division. In this division, smaller batch sizes than in the TE division are handled, for most customers are eager to find out how well their chips function as of that point and whether they are ready for mass-production. Every single chip could contain valuable information about how well the entire batch is functioning. There are various tests that simulate environmental influences to measure the functionality and stress-tests that measure the reliability of a chip. Some examples of environmental tests are Shock, Vibration, Bump, Temperature and humidity tests. These show the customer exactly what a chip can endure. The stress-tests are designed to measure the reliability of a chip under constant specific circumstances. These tests measure the early life failure rate by exposure to high temperature. This enables simulation of the first two years in the lifespan of a chip. The chips can also be submitted to a dramatic sudden in- or decrease in temperature for avian simulation. Also there is the Burn-In section, which exposes a batch of ICs to high temperatures for several hours, in order to simulate the first two years of the lifespan of a chip. This way the chips that would show defects during the first two years under normal circumstances are picked out preventively.

3.3 Market

Company X NV. is a test house and laboratory for optic- and micro-electronic analysis. The qualification and tests Company X is able to perform are visible in figure 3.

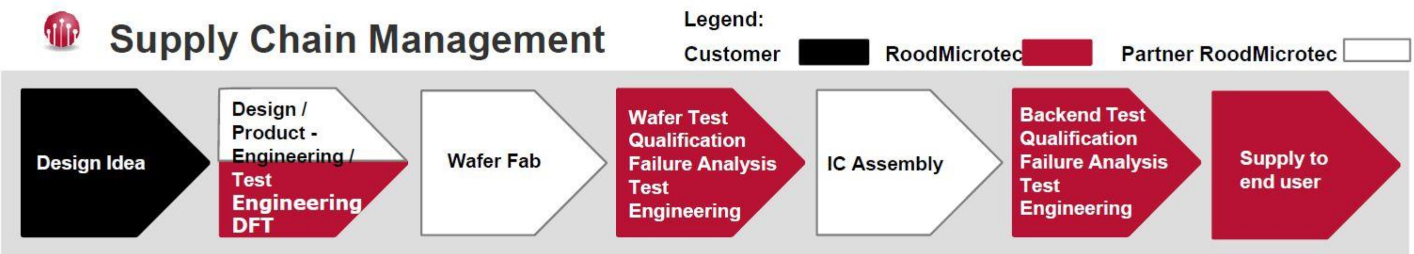

Figure 3: Supply Chain Management (RoodMicrotec.com)

In the clientele, Company X sees a decline in large order customers and a growth in small order customers. Large order customers are taking testing and qualification matters in-house in order to decrease costs go to the competition or the chips they were using got outdated. Smaller companies have always been a part of the customers for Company X, but their turnover was never based on small companies alone. This is becoming more and more the case.

The Semiconductor Industry Association (SIA) forecasts a limited growth for the industry in 2012 at 2.6% and a moderate growth at 5.8% in 2013. This growth will be concentrated in Asia. Europe will lag behind.

Directing the full supply chain is a trend of the last few years, in order to reduce logistic and handling costs, next to reducing inventory cost.

Other factors that have to be taken into account when reviewing the current position of any organization is the political and economic situation. There is a lot of political uncertainty in Europe, about the euro and the Grexit. This is causing a decline in economic growth in Europe, which affects the turnover numbers for every company operating in Europe. Figure 4 illustrates the dependency of Company X on the European economy. The small market share in Asia offers Company X little comfort in the turnover for the upcoming year. This prospect emphasizes the need to enforce action in the areas Company X can influence.

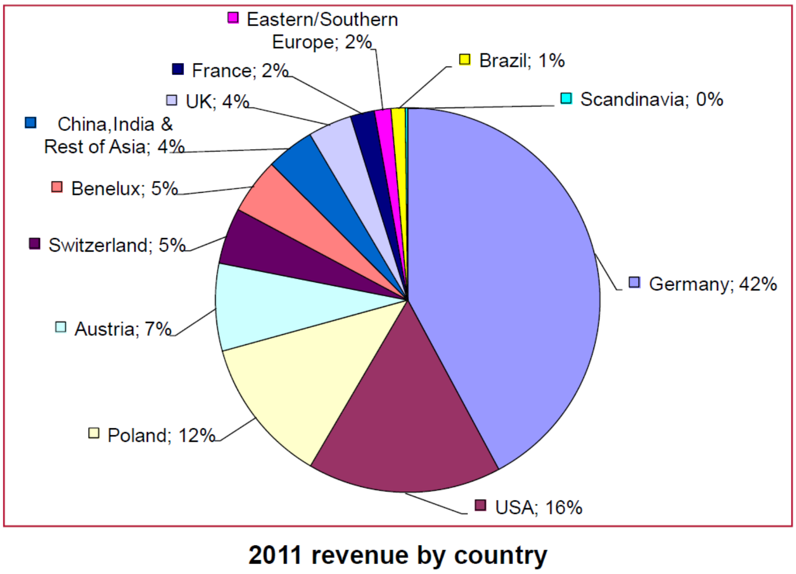

Figure 4: Revenues in the semiconductor market per country (RoodMicrotec.com)

In chapter 1, the organizational structure of Company X N.V. is described and an overview of the company is given. This present chapter is dedicated to describe the current situation, to be able to understand the processes, planning, scheduling and workflows which take place in the production and testing facility of Company X Place y. The Qualification and Reliability department will be described first, as this department was the main focus of the research. For comparison, the Test Engineering and Programming departments will be described, including processes, planning, scheduling and workflows. The purpose of this chapter is to obtain an insight in the production floor, to solve some of the transparency issues encountered and described in the previous chapter. At the end of the chapter, full understanding about the planning and workflows at Company X should be obtained. The company point of view will also be evaluated regarding these departments. It is important to note that the current situation is in place since a few years now, as a result of the merger in 2008.

Some of the customers of Company X are the BMW Group, Philips, Bosch, Continental, Volkswagen and Thales. Although some of these customers tried the cheaper Chinese market for testing and qualification, the German quality and service brought them back to Company X. The demands of these customers are of a high standard. An example of this is the need for a high quality chip which orders the release of your air bag. After fifteen years, the chip should still work, even when the car has driven through the Sahara desert three times, ensuring your safety.

3.4 General Workflow Description Q&R, TE, Programming

To get insight in the work process at Company X, we will use Company X's own guidelines toward their workflow process. This is an addition and more in depth knowledge than the workflow portrayed in 3.1.

The general work process in Company X for the departments of Qualification and Reliability, Test Engineering and Programming can be described using an eight step approach. These eight steps are included in appendix D. The description per workflow is as follows.

1. Customer Order Incoming, Goods Incoming and Incoming inspection

Orders from customers come in via telephone, e-mail, mail, earlier set contracts, or any other communication channel. The specifications brought with an order are the delivery date, the amount of pieces that have to be tested and the tests that should be performed on the pieces. Sales and Customer Service are responsible

Goods incoming controls the incoming packages from the customers on completeness and damages. They also register the incoming goods and forward the goods to Incoming inspection. Responsible for this process is Warehouse and Receiving.

Incoming inspection is responsible for the first tests on the incoming products, a consistency check of the products with the incoming papers. Detecting quantity, week code, batch number, packaging type and housing form. A random sample is taken from the incoming batch, controlling it for minor mechanical defects such as bent pins. The goods are repacked in Electro Static Discharge (ESD) cardboard box. The delivery papers are forwarded to Customer Service, the goods are forwarded to the warehouse.

2. Accepting Order

The Customer Service checks the customer order and the shipping protocol. The customer order specifications, product and service data, is entered in the ERP-System. This data is also forwarded to the production planning system (PPS).

3. Generation Production order proposal

The Master Production Schedule and the TAS Database convert the customer order automatically into a production order with a contract proposal. Sample orders from the ERP-system are used to include housing and general level operations or processes and their basic information. This basic information includes workplace, average waiting times, average processing times and average setup times. It also takes available company resources into account. The TAS database is the system in which this information about the sample orders is available. The planning department and the ERP-system are responsible for this step.

4. Order Scheduling and Transport

Examination of the data contained in the proposal. This is done with the aid of databases, operating procedures and consultations with Customer Service, Sales, Engineering, Manufacturing, Mechanics and customers if necessary. After clarification of any inconsistencies, the order is released and a delivery date is coordinated while considering manufacturing capabilities and customer preferences. The creation of the production documents and the test plan is automatically based on the approval and scheduling of the job. The responsible department is the planning.

Incoming Inspection combines the production documents with the goods and the plans for the test processes. The combined package is then transported to the first step in the production process according to the plan. Incoming Inspection is responsible.

5. Production

After review of the work list, the goods from Incoming Inspection are extracted and processed. Production uses hand trolleys to move the goods around. Feedback about the amount of failures, who processed the item, processing times is inserted in the Production Planning and Scheduling system, adding to the TAS database data. Dependent on the orders, the chips might only see Test Engineering, Qualification and Reliability or Programming, or a combination of the three. These departments are responsible for a correct handling of the customer order.

6. Packaging

The packaging of the goods is done according to customer specifications. Completing the production process automatically puts the reporting data for the customer in the QC-database. Storage and Handling generated during the production is also enclosed in the reporting data. The accompanying documents are forwarded, together with the test report, to Customer Service. The goods are prepared for shipment.

7. Order completion / Transport

Customer Service is responsible for the order completion. The creation and delivery of certain handling papers, for customs documents requirements set by some countries is taken care of. The shipping department prints the shipping documents. Invoicing is also done in this step.

8. Data maintenance

Maintenance of master data in VKS (sales system) and PPS (production planning system)

To complete the production schedule that is produced in step 4 of the general work flow, Company X uses a shift planning. The production floor is segmented into three different shifts, covering almost the entire 24 hours of a day. The processes are long lasting and have a chance of breakdown at any given moment. Because breakdowns are costly and, as in every service based company, time lost can’t be retrieved.

3.5 Data systems

As described in the section above and visible in appendix D, there are several systems in place to support the work flow on the production floor. The current Enterprise Resource Planning (ERP) system is called Oxaion, based on the AS/400 system of IBM. This system is currently in place for about twenty years and constantly tweaked. As it is enterprise wide, the database varies from information for sales to information for the warehouse about shipping documents. For the purpose of this research, the assumption can be made that the order is already requested and waiting for approval and scheduling. The orders are planned using the information provided by the Sales team about the order. If the order calculations show profit and the schedule allows it, an order is planned using the Project planning system (PPS). When the order is scheduled, that means the order has been approved by the ERP system. The information used to allow a correct estimate of the necessary time is saved in the TAS-database, keeping track of average waiting and production times. In case of break downs and repair times, the AS/400 based system can't process that information and gives an incorrect overview of current affairs.

While the system is available to the whole production floor, only Test Engineering and Programming make extensive use of the ERP system, scheduling and planning orders. The Qualification and Reliability department makes use of excel sheets to plan their customer orders, although some of the plans for a specific customer come from the scheduling in the ERP system. While it is known that ERP systems are slow and bulky, there is a lot of information in the system. With the customer orders active, it is possible to get an overview of the needed employee hours, the usage of machinery and the status of an order in a few clicks. With datasheets from Excel, this transparency is difficult to achieve.

The process of replacing the Oxaion AS/400 system is in motion. As of October, Company X will start to use a new system, named Apollo. This gives new opportunities as well as challenges to Company X. As normal ERP systems will stay in place for a long period of time, a proper implementation with respect to key success factors should be taken into account.

3.6 Conclusion

Company X is a high tech company, with its production situated in the south of Germany. As a result of several mergers and a changing market, Company X has to evolve to stay financially healthy and competitive. While the trend in the market is to start the test processes for large batches in house, Company X can offer value by guiding the process as a supply chain consultant. The general workflow in the company is clear, although the management information is limited due to the high amounts of information silos of the different databases. The new ERP system will be an opportunity in the competitive market.

4. Current situation in Q&R / Burn In

The Qualification and Reliability (Q&R) department had a 15% share in the revenue over 2011.[1] The tests and processes carried out by the Q&R department are typically early in the production of the Integrated Circuits (ICs). An IC is developed by a customer, possibly in cooperation with Company X. After developing the IC, Qualification & Reliability perform tests on these ICs. These processes are described in 4.1 and vary from simply baking a chip for a certain amount of time, to destructive tests, in order to see how much a developed chip can handle by destroying the ICs in the process. The numbers of ICs that are tested vary from tens to several hundred at the same time. The company view on this process is based on project management, with every customer order representing a new project and a specific approach.

4.1 Processes of Qualification and Reliability

In the Qualification & Reliability area there are different qualification areas for chips that are meant for different industries. The aerospace and military areas are under far stricter regulations than for example chips for mobile phones or toys. In the next segment, the qualification for the automobile industry will be described, as these processes include most of the processes that are performed at Q&R. In table 1, the acronyms and corresponding names of these processes are shown.

Temperature Tests	
HTSL	High Temperature Storage Life
Lifespan Tests	
HTOL	High Temperature Operating Life
BI	Burn In
ELFR	Early Life Failure Rate
Stress Systems	
PTC	Power Temperature Cycling
THB	Temperature Humidity Based
HTRB	High Temperature Reversed Bias
HAST	High Accelerated Stress Test
Environmental Tests	
TC	Temperature Cycling
UHST	Unbiased HAST
AC	Autoclave
Mechanical Tests	
CA	Constant Acceleration
GL	Gate Leakage
Electronical Tests	
EDR	Electronic Data Retention
ED	Electrical Diagnosis

Table 1: The processes in AEC – Q100

These processes test the chips at certain temperatures, humidity, voltage and sudden humidity and temperature changes. The duration of these processes vary from forty minutes up to 1,000 hours.

[1] https://www.roodmicrotec.com/fileadmin/user_upload/Investor_Relations/Shareholders_Meeting/Shareholders_Meeting_2012/20120426_AVA_Presentation_Final.pdf

Per test, however, the times are predefined by either the qualification form or customer desires. In appendix E a more detailed description is given of how the processes differ and what type of machines are used for these tests.

Lifespan Tests

An important part of the qualification tests is knowledge about the lifespan of the chips. Like almost any other product, chips have a certain lifespan, roughly corresponding to the bathtub-curve. During the first period of time, there will be a higher failure rate due to 'infant mortality' (Hartzell, 2011). The next period of time is the 'Useful life period' where there will be a low, constant failure rate. During the last period of time, the chips will be worn out and are in 'end of life stage'. In figure 5, this lifespan is shown where the correspondence with the common bathtub is noticeable, hence the name.

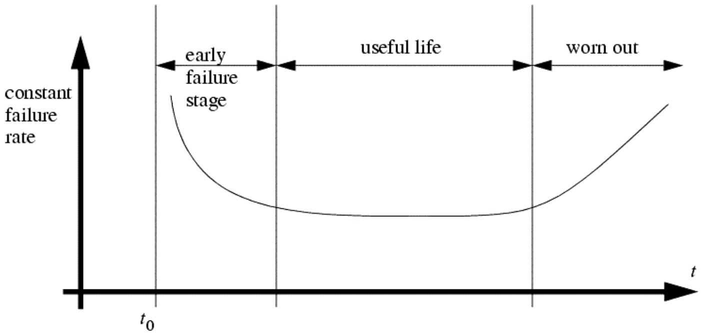

Figure 5: Bathtub curve (eNotes professional engineering topics)

In the semiconductor industry, submitting the products to a high temperature for a certain amount of time simulates an accelerated lifespan, meaning that chips that have been exposed to a temperature of 125°C for twelve hours show the same deterioration as chips that have been exposed to normal circumstances for two years. At Q&R, the test ELFR determines the percentage of dropouts during the 'early failure stage', by simulating the first two years of the lifespan. HTOL determines the dropout rate far into the 'worn out stage'. These tests are both used in the research stage of a product, before hitting mass production. There also are Burn In tests, which submit large badges of chips to tests, similar to ELFR. The dropouts of these badges are simply put bad products, and the others are used for production. This way, the 'early failure stage' is circumvented and the products go directly into the 'useful life period'.

Temperature Tests

The only straight forward temperature qualification in the portfolio of Company X is High Temperature Storage Life (HTSL). HTSL testing is used to determine the influence of time and temperature under storage conditions. The test is performed without the appliance of electrical stress. The test may be destructive, based on the duration, packaging and temperature used.

Stress Systems

In Power Temperature Cycling (PTC), semiconductor devices are alternatively subject to extremely high and low temperatures. Periodically, a current is applied to the semiconductor. At Company X, the temperatures vary from -40°C to +85°C. Temperature Humidity Based (THB) tests are a large part of the Q&R operations. This test measures the corrosion resistance of the circuits. The THB test tests the circuitry in a way that is similar to tropical environments. These tests typically last 1000h. A shorter alternative to the THB test is the Highly Accelerated Stress Test (HAST). This test typically takes 96h to complete, while testing it on the same areas as THB. Although it's increase in popularity, in high demanding environments such as the automotive industry, a HAST alone is not sufficient enough to declare certain circuits safe to use.

Environmental Tests

Temperature Cycling makes use of a change in temperature to test the circuitry. After a cold start of about -60°C, the temperature is increased to up to +200°C. Air flow is constant and rapid to assure a fast acclimatization of the specific temperature. One cycle consists of a drop in temperature for a minimum period and a spike in temperature for a minimum period. Test durations consist of a 1000 cycles, typically. The Autoclave (AC) test focuses on moisture penetration and the effects of galvanic corrosion in circuitry. Standard conditions are +121°C, 100% relative humidity and a duration of 96 hours. Failure due to corrosion is the failure that is expected from this test. AC is a destructive test, meaning that there is a high probability of destroying the tested chips. Unbiased Highly Accelerated Stress Test (UHST) is a test in which the non-hermetically packaged chip is exposed to humid environments. Temperature and humidity are applied, while making sure a non-condensing environment is maintained, to penetrate the external protective material with moisture.

Mechanical Tests

Constant Acceleration (CA) is used to expose semiconductor devices to constant acceleration. The purpose is to expose mechanical and structural deficiencies in the packaging of semiconductors. CA can be used as both a destructive test or on a lower stress level. Gate Leakage (GL) is the process in which the electrical current through a chip is tested. The incoming and outgoing current is measured. If there is any discrepancy between these numbers, it is most likely due to incorrect connections of tin in the chip. This test prevents malfunction due to unstable connections in the chips or on the electronic circuits.

4.2 Test Chambers

The production plant of Company X consists of a large factory floor within the building, with various different test chambers. This factory outlay is available in Appendix C. Certain processes described above can be executed through different test chambers. The important variables to be able to assign a test chamber to a process are the temperature, the humidity, the length of the test, electrical current and climatic changes. The category that can't be described by these variables is the mechanical test, such as the Constant Acceleration test. While the overview of machinery given in appendix E combines certain processes with certain test chambers, more combinations could be made dependant on the variables mentioned before. The process of Burn-In, Early Life Failure Rate and High Temperature Operating Life are all very similar, for example. These processes can be executed by the same test chamber, as long as the test chamber can handle the temperature needed.

The conditions, in which the ICs are tested, make sure that the ICs will run after several years in harsh environments. As a result, the testing is not only harsh for the chips, the test chambers are also subject to wear and durability loss. To make sure the test chambers operate between their deviation margins, the machinery is calibrated once in a while. This can happen once a year, once every half year, once in two months or only when the machine is being used. The last scenario only happens when the test performed by the test chamber is not performed often and therefore not profitable to calibrate. The calibration process follows a procedure described in the Lotus Notes system, the process databank of Company X. Depending on the test chamber that is calibrated, the process takes one to two days. The result is a deviation on the standard input for variables, mostly temperature, in the machine. For example, to obtain 125 °C, 126 °C should be inserted in the machine to make up for the wear and to achieve the real temperature of 125 °C.

Burn-In Boards are an important part of the equipment. This particular part of the equipment is used to hold the ICs in place and to have access to the status of the chip, working or defect, inside the test machines. These boards come in various sizes and are adjusted to the size of the ICs that need to be tested. The amount of chips on a Burn-In Board varies from around ten to over fifty chips per board. While there is a machine available in the Q&R department to automatically load and unload the boards, most of the boards are manually loaded and unloaded. The machine simply can't handle all the sizes of boards and chips. As with the calibration of test chambers, the Burn-In Boards also need to be calibrated for bad sockets. Bad sockets will be marked and when the number of broken sockets reaches a tipping point, new boards will be ordered. While it is necessary to have the boards for certain tests, Company X and the customer make an arrangement for the Burn-In Boards. As stated, there are a lot of different types of chips, which mostly vary with the customer. The customer needs a specific board to test their specific chips. As a result, the boards are mostly bought by the customers, for specific tests. It should be noted that these boards are expensive equipment. Although the test chambers could be seen as the bottle neck, the lack of boards makes it difficult to build up an inventory before the specific test step in which these boards are needed in the test chambers. Due to the high variety of boards and the high costs per board, this solution to make full use of the test chambers is an expensive one.

With certain test chambers not being operative and some being calibrated or waiting on a calibration, Qualification and Reliability relies on a few core test chambers which take care of most of the testing processes. These machines are susceptible to failure. In case of a failure, the technicians have to take care of the problem. The role of a technician will be further described in the next paragraph. The problem with the test chambers could be fixed in under an hour, or it could take up to several days. This depends on the speed with which the problem can be identified and if the necessary pieces to repair the machines are available. If this is not the case, the request for new parts has to go through procurement and this can take up to several days, with shipping and availability at the supplier and the priorities in the procurement department, frustrating the production process.

4.3 Employees in the Qualification and Reliability Department

Q&R + Burn In team consists of thirteen employees. In appendix F there is an organizational chart of the Q&R department, representing the employees currently available. Due to the fact that most test chambers run for days and the chambers need to be inspected every once in a while to make sure the machines don't break down, the Q&R department uses a shift planning. In case of a break down, the right people should be notified. This chapter will go into depth more specifically for each employee specifics. The chain of command is represented by the sequence in which the descriptions are presented.

Engineer

The engineers are the managers on the Q&R floor. The specific order plan produced by the technicians is approved by the engineers, according to ISO requirements. The calculation of order costs and profit is done by the engineers. Setting up machines and programming are also part of the activities of engineers.

Technician

The technicians of Qualification and Reliability fulfil the role as a service worker. The responsibilities consist of preparing the test planning of orders, calibration of the test chambers, programming test chambers, setup for tests, performing maintenance on the test chambers and to keep the test chambers running. As the test chambers are not flexible in their process, a test for 1000h needs 1000h to run, it is vital to keep the chambers running during tests, to keep up with order calculation and the proposed planning. As explained in 4.3, the process could be delayed by days as a result. For the calibration and maintenance of the machinery, in-depth knowledge is needed about the machinery. In case of breakdowns, knowledge and daily handling of the machinery gives more insight in how the failure should be repaired.

Operator

An operator in the Q&R department is responsible for the basic activities in the Q&R test field. These activities range from electrical testing to executing fine leakage tests. As stated in paragraphs 4.1 and 4.2 about the machinery, not every test chamber is the same and requires the same attention. For example, with a Gate leakage test or a constant acceleration test, a Burn-In Board is not necessary and the test only consists of the operator performing a series of tasks to complete the test. These processes, together with incoming and visual inspections, electrical tests and packaging and shipment, are the core activities executed by an operator in the Q&R department. Electrical tests are done manually in this case. Incoming and visual inspections are used to make sure the products are ready to be tested and mounted properly in the sockets or otherwise correctly prepared for the test chambers. Packaging and shipment is the last step in the Q&R department, controlling if the order is complete and wrapping it properly, in the majority of the cases this means an Electro Static Discharge (ESD) packing.

Company X is a company that tests high end circuitry. It is therefore very important to have the right circumstances to be a reliable test house, a status which is attained through the ISO certificates. These certificates also demand a certain amount of archiving and a way of reporting, adjusted to the customer wishes. Due to the fact that Q&R is not working with an ERP input system, the duration of activities has to be monitored by hand by the operator, together with the amount of passes and failures in a test. After the completion of the order, the test planning is returned to the Q&R office where a technician enters the data into the digital test planning, preparing it for reporting to the customer. After completion, the printed test planning is archived together with all the other test plans, based on recency.

Board loader

For several of the processes and tests in the Qualification and Reliability department, Burn-In boards are used to test the circuitry. The sole activity is loading and unloading of boards, before and after the test chambers. As the boards are expensive and every board is tied to a specific measurement of chips, there is a certain cap on the boards that can be prepared for the test chambers. Next to full time employees, temporary workers can be used for this production process. In the current situation, this possibility is unavailable as there is a process in place called 'kurzarbeit', reducing the working hours of the employees to prevent lay-offs. This measure legally prevents Company X to hire temporary workers. Employees working on the loading of boards also have the ability to perform basic operating jobs, such as manual electrical tests or incoming inspections.

4.4 Planning Qualification and Reliability

To schedule the planning of Qualification and Reliability, the department uses an excel datasheet. For every order, there is a "Prüfplan". An example can be found in appendix G. The combination of all the test plans is the basis for the excel datasheet used to plan every order, test chamber and employee. After speaking with the technicians of Q&R, it was clear that the current mind set is that Q&Rs activities differ too much from the regular activities within Company X, and are too variable per distinctive case, to be integrated in the ERP database. There currently is one exception; Infineon is one of their customers and they issue the same order every time, so that order is standardized and inserted within Oxaion.

Planning data is not only available in the Excel sheet. To quickly gain insight in the current use of machinery and workload, there are two Microsoft Project files in use. Upon researching these files and comparing the MS Project as well as the Excel sheet to the running orders, we noticed certain discrepancies. An earlier research at Company X used the Microsoft Projects to plan all the orders, test chambers and employees. That version was complete for the period it was created, but usage stopped after the main driver of the project left. The current MS Project files are not complete and a shallow representative of that first initiative. The most up to date file is the Excel datasheet mentioned earlier. As for the planning in Q&R, it is based on a pull point of view. Only after a customer places an order, the production is started. As the process is about testing the ICs provided by the customer, the process can only start when the chips are received.

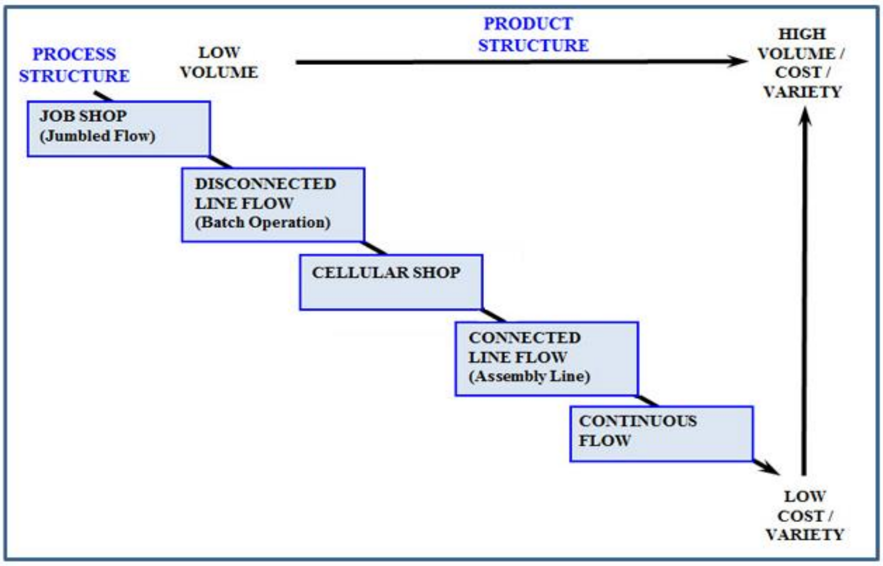

Figure 6: Process structure

The variable machinery and the variety of processes describe the process structure which is place at the Q&R department. In terms of naming the process structure, we identify the Q&R department as a 'Disconnected Line Flow'[2]. The usage of the chambers and board loaders are an example of this process structure.

[2] https://acc.dau.mil/communitybrowser.aspx?id=520799

4.5 Conclusion

We have had an in depth look at the Quality and Reliability department. The amount of machinery used and the high variety of processes, which can be described as a 'Disconnected Line Flow' (figure 6), caught our attention. The same goes for the high hierarchical culture that is in place at the department. The feelings from the employees towards the other departments and the methods used by the other departments to keep their department running are not always positive and don't contribute towards a joined company culture. Lastly, the overview gained with Microsoft Excel and the MS Project file is inadequate due to the effort needed to obtain the overview. The discrepancies between Excel and the MS project file and the margin for human errors encourages the feeling to incorporate something more sophisticated and trustworthy. This also helps the archiving for the ISO and other safety or quality regulations. As it stands, there are opportunities for further enhancements in the Q&R department.

5. Current situation Test Engineering & Programming

The Test Engineering department and Programming department had a 45% share in the revenue over 2011.[3] The tests carried out by the Test Engineering department are typically done when the ICs are in production. The processes are designed to filter out the early failures from the production process. The curve that describes these failures is also known as the bathtub curve (Hartzell, 2011). The batch size differs from 500 pieces to up to 50.000 pieces that have to be tested. As the process of testing a chip with an electrical test doesn't take long, the process is looked at as a mere production process, with given times for every test. Programming is even further down the production line. As the amount of chips is in the same range in Programming as in Test Engineering, the processes are more basic in comparison to the Qualification and Reliability department and both TE as the Programming department make extensive use of the ERP system, Oxaion. Therefor the two departments are researched as a whole.

5.1 Processes TE & PSS

The activities within the division of Test Engineering & Programming can be divided among roughly three separate processes; electrical and wafer tests and programming. These three activities for the core of the division and generate most turnover for Company X.

Electrical Tests

The main processes taken place in the Test Engineering department are Electrical Tests. These Electrical Tests heat or cool the chip to a certain temperature, after which the chip is tested with an electrical current to see if it still functions. These temperatures may vary from minus 40 degrees Celsius to plus 125 degrees Celsius. Next to the difference in temperature, there is a difference in digital or analogue. The size of the chip does not play a part in the process type, although it is of influence to the machine type.

Wafer Tests

Although electrical tests are a big part of the turnover in Test Engineering, it is not the only process. Wafer inspection and wafer failure tests are also part of the testing range of Company X. Dependent of the status of the producer, Company X helps with the tests before the wafers are taken into production or assesses the wafers when they have been taken into production. High Temperature tests for wafers could also be executed.

Programming

The third section of the production floor is used for programming of the chips. Programming is the process of preparing the chip for the actual use of the customer. Examples are the chips that allow your airbag to inflate or to make sure your phone turns on when you want it to. Programming is typically done after any sort of testing. When you test after programming and a chip fails the test, the programming on the chip was a redundant process, resulting in production time loss. With more expensive chips, it may occur that the chips are being recycled. Before being able to program these chips with new logical schemes, the data from the previous programming is erased.

[3] https://www.roodmicrotec.com/fileadmin/user_upload/Investor_Relations/Shareholders_Meeting/Shareholders_Meeting_2012/20120426_AVA_Presentation_Final.pdf

5.2 Machinery

The testing in Test Engineering is mass production. The machinery of a single test engineering module consists of a handler, a test program run by the test chamber and a transmitter which is the connection between the handler and the test chamber. The machines are equipped to process the chips automatically. As stated in the previous section, the measurements of the chips are of influence on the machinery that can be used. Although it is possible to switch the handling machines to be able to handle bigger or smaller chips, this is an employee intensive process, which could take up to a day of work. A slight deviation in this setup could be the cause for constant jams in the testing process, which lengthens the testing process a fair amount. The machines are also influenced by the method of inserting the chips. The chips could be, dependent on customer orders, packed in tubes or in a rectangular container.

The machines for wafer tests are only available for high temperature wafer tests or qualifying said wafers. Inspections are mostly done with a microscope or lens. When qualifying or testing the wafers, the same setup as with Electrical tests is used. A handler, a test chamber and a transmitter are also needed for these tests. Examples of these types of machinery, for the Electrical and wafer tests can be found in appendix H.

The machinery in the PSS area of the production floor consists of handlers, computers containing the logic data and machines to wipe chips clean during the removal process. Most of the handling machines operate in the same way as the machines in the Test Engineering department. Once in a while, a new feed of chips has to be inserted, in the case of programming, the building blocks (chips), are rolled onto from and onto a wheel.

5.3 Employees in the Test Engineering and Programming department

The Test Engineering department consists of twenty employees. The Programming department consists of eleven employees. In appendix F there is an organizational chart of the Test Engineering and Programming department, representing the employees currently available. As the amount of chips can run into thousands and the machinery is mostly semi-automatic, the TE and PSS department also use a shift planning for their employees. This section will go into depth more specifically for each employee specifics. The chain of command is represented by the sequence in which the descriptions are presented.

Engineer

The engineers in the TE and PSS department also fulfil the role of manager. They oversee the general production and are responsible for the department. Together with customers, the engineers design the specific programs or test sequences for the purposes needed by the customer. Small tests and configurations are done by engineers to provide the information for the customer on the envisioned test. In cases of heavy machine failures, the decisions are made by the engineers.

Technician

The technician is responsible for the everyday maintenance of the machinery in the TE and PSS department. As with the Q&R department, repairing and maintaining the machinery is the number one activity in the schedule of the technician. As described in 4.3, the machinery is fitted to process only a certain type of chips, regarding entry method and size of the given ICs. Dependent on the machine, it can be adjusted to support another type of chip. This measure is time consuming for both the technician and for the production line as a whole. To be able to service and maintain, as well as repair, the machinery most efficient, a deep knowledge of the machinery is needed. This is currently obtained by the technician by working every day on the specific machinery. The process of calibration is also carried out by the technician.

Operator

The operator is the basic employee of the TE and PSS department. As the operator in the Q&R department, the operator is responsible for running the machines. The work can be described as a basic production line. The main activity is to make sure that the electrical test machines are running. While the machinery feeds itself after the chips are inserted, through tubes or squares, the probability of jamming or failure may occur. There are up to fifteen electrical tests running at the same time. As with all processes, not every production run is as smooth as the next. It might occur that the customer tested some of the chips themselves already, bending the feet of the chip lightly in the process. As a result, a process that should seemingly go smooth turns out to take up a lot of time out of the day of an operator. In the Test Engineering department, from six to twelve processes run simultaneously most of the time.

5.4 Planning Test Engineering and Programming

The general workflow of the processes is discussed in section 3.4. In order to do obtain an insight in this planning process in TE and PSS, this section is dedicated to steps 3, 4 and 5 from the general workflow, respectively General Order production proposal, Order Scheduling and the Production itself.

The process of planning and scheduling the resources available in the Test and Programming department is done through the use of the ERP system, Oxaion. The customer order enters through the Sales part of the ERP system, VKS. Thereafter it is checked on the needed machinery, inventory, production hours and delivery date. After this control is completed and no errors turn up, the order becomes part of the production planning system (PPS). If there are complications, contact with the customer is sought to discuss the problems that arose and to find possible solutions. After tweaking the specifications, the order continues as a normal order. As a result of the PPS, the orders are scheduled to be ready on the agreed delivery date, working backwards to establish the needed processes. The resources needed to produce the customer orders are already taken into account, delivering a full scheduling of orders for Test & Programming departments. This includes the amount of operator hours needed for the next day, week or month. The current orders can be scheduled, as well as the amount of technicians which are needed to take care of breakdowns and calibrations. It is also known what the wait times will be for the specific order as well as the overview of the machinery which is in use in the Test department. This can be done because the process in Test Engineering mainly consists of electrical tests. These electrical tests can be run almost automatic, with a minimum amount of variables.

The planning and process structure of the TE and PSS department can be identified as a "Cellular Shop"[4] from figure 7. The variety in machinery is limited and the changes in the machinery setup are time intensive in the TE department. Machine handling qualities from operators are limited to a few

[4] https://acc.dau.mil/communitybrowser.aspx?id=520799

repetitive tasks. Although these factors indicate a “Connected Line Flow”, we don’t identify the production process as an assembly line due to the different workstations. The variety in products and the batch type handling of the machinery identifies the TE department as a “Cellular Shop”.

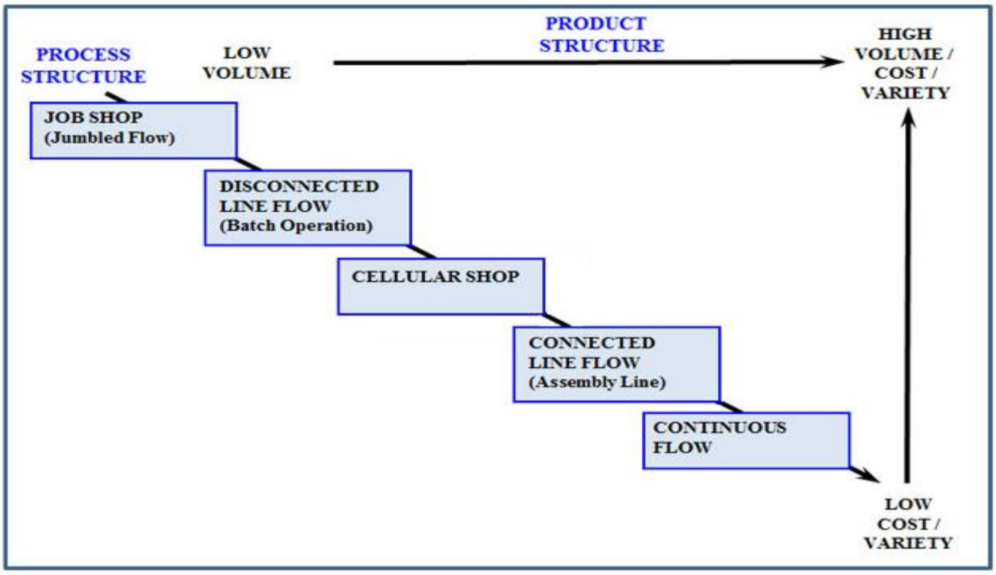

Figure 7: Process structure

5.5 Conclusion

The TE and PSS departments are further in the production line of a new Integrated Circuit than the Q&R department is (see figure 3). The Process structure of the TE and PSS department can be identified with the “Cellular Shop” in figure 7. Machinery is limited and the changes in the machinery setup are time intensive in the TE department. When the ‘assembly line’ is complete, however, the production process is a continuous flow. There is a very hierarchical work relationship at TE and PSS, with the Engineers responsible for customer relations and designers of the tests, the Technicians as the control and repairer on the production floor and the Operators as the labour force. The production flow is controlled via the ERP system and that ensures on time delivery in most cases, or at least a forecast of when certain orders are finished. The ERP system can give management information on stock levels, production cycles, downtime from machinery and accurate labour hours per activity. The ERP system does this all automatically as long as the data entered is correct.

The comparison to research the potential overlap between the Q&R department and the TE and PSS department on machinery, employees and planning is done in chapter 6.

6. Q&R compared to TE and Programming

In this chapter, the two divisions of Q&R and TE and Programming are being compared to each other to point out the possibilities between the divisions. With the implementation of the new Apollo ERP system, significant changes will come to the everyday activities within Company X. This change in scenery is the perfect opportunity for Company X to make sure Q&R and TE are fully integrated within the organization's ERP system. In order to achieve this, the similarities and differences among these divisions are pointed out.

6.1 Processes and machinery compared

Currently Company X views the Qualification and Reliability department as a project based 'batch type' of manufacturing, with a clear beginning and end in every project, with every process more or less identified as a unique process. Test Engineering and Programming are considered more of an 'assembly line' production, with less complicated tests and a higher amount of chips that are processed.

Machinery

There is a wide array of machinery available in the Q&R department, with the addition that certain tests can be performed by more than one machine as is visible in appendix E. At TE the machines can be adjusted and prepared for a certain type and size of chip, which increases the production capacities. The machinery reflects the difference in the nature of the processes in Q&R and TE. This means that Q&R uses test chambers, for TE the testing is done piece by piece, semi-automatic. Although there are very clear differences in the machinery, the common ground can be found in the failures of the machinery. In both departments, failures delay the production process significantly and have to be repaired by technicians, who should have the knowledge to work with the specific machinery.

Process flow

While it is a given that the Q&R processes are different from the Test Engineering processes, there is also a certain amount of repetitiveness. This is a logical conclusion from the fact that there are certain routines and habits that occur in the Q&R department. After interviewing employees of both Q&R and TE, it became clear that the total amount of processes in Q&R was higher and more differentiated than in TE. Although the amount of processes was higher, the procedure and description of the procedure was similar. There is a standard test plan that is used in both Q&R and TE, next to that the Q&R department has an additional test plan. This additional test plan is used in the Q&R department to specify the precise temperature, humidity and repetitions in the test chambers. This additional plan is also used as a report method from the Q&R department to their customers, while the TE department uses standardized reports in Excel which are based on the data from the ERP system. The reports from Q&R are the result of manual input of the data in the report form. In this process, the additional test plan is used as the basis for the report to the customers. The usage of test plans and process flows from ERP in the different production departments is illustrated in appendix G (Q&R) and appendix I (TE).

6.2 Employees compared

The similarities between the types of workers are noticeable. The three levels of hierarchy in the production departments are the engineers, the technicians and the operators.

On manager level, both of the departments are run by the engineers. The engineers are responsible for the decision making and are involved with higher management. The engineer discusses with customers to obtain the best testing sequence and detail. Also, the engineers make the order calculations and are the responsible party for the planning and scheduling of the orders and the quality and delivery to the customer, i.e. the person in charge of the department.

The technician is also very similar in both departments. Although the activities and responsibilities are equal, the machinery on which the service has to be carried out is not the same. In depth knowledge of the machinery is helpful to obtain a quick insight in what is needed to repair or replace in the machine, which comes in handy as well when the machinery needs to be calibrated.

In the descriptions in chapter 4 and 5 of the production departments, we saw that the tasks of an operator don't change much. The main objective is to keep the production line up and running and to control the safety and continuity. Through regulations, a minimum number of employees are needed to run the operations for certain machinery. Although the machinery is different, the controlling of operations and keeping the machines up and running is not a problem and is a process that can be done by a 'pool' of employees, taken from Q&R and TE.

If we now look back at our second research question, the first research question being covered in chapters 3 to 5, we see the following question:

2. "What needs to be done before personnel can be used for both Test and Q&R?"

The ERP system and database are, as stated in the introduction, subject to renewal. The ERP system will be the main focus of research question three. From the above description and table, it seems like the switch up from only being in the Q&R department to being in the pool for Q&R and TE is a possibility. It is important though to note that the cultural differences inside the company may cause issues when stepping over them too lightly. The 'we vs them' culture was brought up often during the informal and casual talks with the employees and even more visible during lunch hours in the cafeteria.

6.3 Planning compared

The planning of production, machinery and personnel, is executed with the ERP system, Oxaion. This system can take into account how many days are needed before the products are delivered and give an overview of the production capacity levels during the next week, month and year. Test Engineering makes use of this planning program and the planning is done centrally. For Qualification, the planning is also made in Oxaion. Although the planning is made in Oxaion, the Qualification and Reliability department produces another planning, in Microsoft Excel, and had another one in MS Projects. This additional planning is currently needed to provide the additional room for variables in the processes of the Qualification and Reliability department. For almost every "Prüfplan", Q&R makes an additional schedule. These additional schedules are filled in by hand and controlled manually in the Q&R department. For one specific customer, the Qualification and Reliability department doesn't need an additional schedule, because the variability is low enough to ensure regular use of the same "Prüfplan" from Oxaion. The possibility to incorporate all the processes from the Q&R department to the ERP system is definitely a possibility. It only takes up a lot of work in the setup, due to the high variety of processes, as we have seen in chapter 4 and appendix E.

6.4 Conclusion

We see that it is possible to introduce the Q&R department to the standardized "Prüfplan". For one specific customer, this is already done and the only constraint is the input of the different types of tests and handling that has to be done in Q&R. Although there might be a few dozen different approaches, differences in temperature, length, cycling and more variables from the processes in 4.1, the main idea is that, when introduced in the ERP system, the transparency and efficiency increases. The controlling of worker time is done through the ERP system, the additional planning is not an issue anymore and the processes don't have to be controlled manually anymore. If we look at our second research question, we see that the possibility to exchange workers between Q&R and TE is definitely there. It is important though to keep the cultural differences inside the company in mind when implementing some sort of pooling system. This will be easier on the level of the operators than on the level of the engineers, who are the responsible party for the department. Sailing with two captains on a ship will not further improve the sailing performance. In the contrary, it may likely cause communication and liability problems. Pooling technicians is a difficult one. The in depth knowledge needed to repair certain machinery may outweigh the benefits from pooling this type of employee. A quick summary of the tasks per employees and differences in machinery and planning are shown in table 2.

	Department	
Variables	**Qualification & Reliability**	**Test Engineering**
Machinery	- High variety - Long test times per IC - Small batches	- Low variety - Short test times per IC - Large batches
Operator (**Employees**)	- Loading and unloading boards - Loading and unloading machines - Signalling errors	- Loading and unloading machines - Signalling errors
Technician (**Employees**)	- Maintenance - Repair	- Maintenance - Repair
Engineer (**Employees**)	- Customer contact - Designer of tests - Responsible	- Customer contact - Designer of tests - Responsible
Planning	- Manually in Excel	- Schedule from ERP module PPS

Table 2: Comparison highlights

7. ERP implementation framework

As indicated in the previous chapters, there is a difference in the process planning of the Q&R department and the Test Engineering. There are several possibilities to deal with these changes and fully integrate them into each other. Specific areas of attention to integrate these production lines are the change in culture and a change in management. As there are several ways to transition inside a company, the goal is to set the same standard in both departments. This chapter will contain a research into the world of ERP and the implementation of ERP, as well as the cultural change that is needed to support this new ERP software. We will follow with a success framework for Company X specifically and a general view on the type of industry Company X is in.

7.1 Corporate Culture

The Golden Egg (Sinek, 2010) emphasizes to us that the most important part of the corporate culture is to know 'Why' the company operates. In the example of Apple, they wanted to 'attack the status quo' and provide new options next to the standard that was out there. After the why, it is then the 'How' that should be addressed. In the case of Apple the philosophy continued by 'designing beautiful products that work instinctively and without errors'. Only then, after these two steps are made, the 'What' question arises. 'What' is the end product, in the case of Apple anything from cell phones to desktops, where the 'Why' and 'How' are incorporated in. To have this culture of shared values and a strong corporate identity is critical to facilitate change in an enterprise. (Nah & Delgado, 2006)

7.2 The role of ERP

Due to planned changes, an opportunity rises for Company X in the process of setting a renewed standard for all the production departments. A new ERP system will be in use as of October 2012. While this is not the end goal, it could provide some means to guide the culture of the production departments towards the same goal, an improved output and a corporate culture. With the change in ERP systems for Company X as a base, we will look into the changes we can find in literature to provide Company X means towards the more corporate culture. After reviewing several strategies for ERP change management, we will the search for the best suited strategy for Company X.

The previous paragraphs can be combined and concluded in the sub research question that follows: **Which problems commonly arise when implementing a new ERP system and which of these problems should be taken into consideration by Company X?**

As stated, we will try to support a corporate culture and identity through the use of an ERP implementation. The implementation of ERP is the way to get to the end goal, the corporate culture, and the ERP system is not the goal in itself. However, it may be difficult to attain the right identity in the company in the process of the implementation of the ERP system. In some ways, it should also be guidance to the corporate culture. Therefore, the focus in the following literature will not only be on change management but also on the successful implementation of an ERP system. Next to that, Company X already uses an ERP system. The mere existence of an ERP system already in the company will provide for additional conditions before successfully implementing the new system and in the iterative process a corporate culture.

7.3 ERP Failure

ERP implementations are expensive, lengthy and resource intensive. Due to these constraints, the possibility for failure is significant. In short, we will discuss the main reasons why an ERP implementation is not successful.

Before we can do that, we first have to define what can be seen as a failure in the context of ERP systems and implementations. In a piece of Rockfordconsulting (Ligus, 2004), Ligus tells us that there are five conclusions in ERP implementation which could mean a failure to the company:

(1) Not making the promised return on investment,
(2) Inordinately extending the implementation schedule and start-up date,
(3) Running over budget by unconscionable variances,
(4) Grinding the organization to a crawl pace, or the severest of all consequences,
(5) Stopping production and/or not delivering orders to your customers.

There have been several case studies and articles on the issues responsible for failure in the implementation. A lot of ERP implementation failures are covered in the media, from government projects to multinationals having problems with the ERP systems. Although interesting, articles from news sites are based on hype and numbers and lack depth when it comes to the real issues concerning the implementation of ERP systems as we can see in the article from PC World (Kanaracus, 2011). We have used case studies to determine the origin for failure in ERP implementation.

Case Studies

In a piece of Wong (Wong, Scarbrough, Chau, & Davison, 2005) she states that in her case studies, the common factors for Critical Failure Factors in ERP Implementation are poor consultant effectiveness, poor project management effectiveness and poor quality of Business Process Reengineering (BPR). The complete overview is enclosed in figure 8.

Critical Failure Factors for ERP Implementation	Alpha	Beta	Gamma	Delta
1. ERP system misfit		√	√	√
2. High turnover rate of project team members		√		
3. Over-reliance on heavy customization			√	√
4. Poor consultant effectiveness	√	√	√	√
5. Poor IT infrastructure	√			
6. Poor knowledge transfer		√		√
7. Poor project management effectiveness	√	√	√	√
8. Poor quality of Business Process Re-engineering (BPR)	√	√	√	√
9. Poor quality of testing	√		√	√
10. Poor top management support	√	√	√	
11. Too tight project schedule	√	√		√
12. Unclear concept of the nature and use of ERP system from the users' perspective	√		√	√
13. Unrealistic expectations from top management concerning the ERP System	√			
14. Users' resistance to change		√	√	

Figure 8: Wong 2005, Critical failures for ERP implementation

In a Chinese article on several cases from Xue, (Xue, Liang, Boulton, & Snyder, 2005) the perspective is that of western ERP implementers like SAP and Epicore towards the Chinese market where they are not as dominant as in the rest of the world. While the view of the article is from a western perspective towards the Chinese market, the information is also useful in the context of general failures in the implementation process. The main issues Xue et al. (2005) identified are the issues concerning the Business Process Reengineering and Human Resource Problems. The overview of all the issues regarding the Chinese case studies is enclosed in appendix J.

Important factors for the failure of ERP implementation that can be concluded from the studied cases are poor Business Process Reengineering and the lack of resources, time and money dedicated to the process. There are several factors which influence the implementation process towards a negative outcome. Given these failure factors, there should also be several factors which could improve the implementation process.

7.4 Critical Success Factors

While there are several articles written on the failures in ERP implementations, the more interesting part is to conduct research on how to achieve a successful ERP implementation. In this section, several articles on the Critical Success Factors of ERP implementation (CSF) will be discussed. Before we go over the success factors themselves, we will address the advantages that can be gained from having a successful implementation of an ERP system.

The goal of ERP is stated by Parr (Parr & Shanks, 2000) as follows: *"The goal of ERP software is to*

integrate the information used by accounting, manufacturing, distribution and human resources departments into a computing system, giving management a unified view of its processes."

A software consultant, Consona Corporation ("ERP 101 Research Kit," 2012), sums up the benefits from a successful ERP implementation, in alignment with the goal as stated by Parr & Shanks (2000):

"ERP collects, manages and distributes information across functional boundaries and helps break down information "silos"—those barriers that stand in the way of full cooperation between production, materials, planning, engineering, finance and sales/marketing. The resulting higher quality, reduced time-to-market, shortened lead times, higher productivity and lowered costs can help improve customer service and increase sales and market share as well as margins.

Figure 9: Integration is key in ERP (Spencer, 2013)

Measurements, analysis and simulation capabilities can help companies plan better and react sooner and more effectively to changes in demand, competitive actions, and supply chain disruptions."

To attain these advantages, we will discuss several case studies focusing on the CSFs when implementing ERP systems.

ERP implementation

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Strategic critical success factors	Tactical critical success factors
Top management commitment and support	Balanced team
Visioning and planning	Project team: the best and brightest
Build a business case	Communication plan
Project champion	Empowered decision makers
Implementation strategy and timeframe	Team morale and motivation
Vanilla ERP	Project cost planning and management
Project management	BPR and software configuration
Change management	Legacy system consideration
Managing cultural change	IT infrastructure
	Client consultation
	Selection of ERP
	Consultant selection and relationship
	Training and job redesign
	Troubleshooting/crises management
	Data conversion and integrity
	System testing
	Post-implementation evaluation

Table II. Strategic and tactical CSFs for ERP Implementation

Figure 10: Strategic and Tactical Success Factors (Finney & Corbett, 2007)

Case Studies

From Figure 10 we have an overview provided by (Finney & Corbett, 2007). This overview gives information about the several success factors on tactical and strategical level for the implementation of an ERP system. For their research, Finney & Corbett researched several papers and concluded that most papers only allow a limited amount of success factors to be taken into account. Although this limitation, information can be gathered from this list. Finney & Corbett also quantified the Critical Success Factors (CSF) in amount of citations. This gives even more depth to the value of certain CSFs. We can derive the most important factors according to Finney & Corbett from these citations, stated in figure 11. The top five categories are as follows; top management commitment, change management, business process reengineering and software configuration, training and job redesign and the best possible project team. It is important to note that these are only citations and it gives a small foresight in the CSFs we are most likely to encounter in the case studies.

BPMJ
13,3

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Table III. Frequency analysis of CSFs in literature

CSF category	Number of instances cited in literature
Top management commitment and support	25
Change management	25
BPR and software configuration	23
Training and job redesign	23
Project team: the best and brightest	21
Implementation strategy and timeframe	17
Consultant selection and relationship	16
Visioning and planning	15
Balanced team	12
Project champion	10
Communication plan	10
IT infrastructure	8
Managing cultural change	7
Post-implementation evaluation	7
Selection of ERP	7
Team morale and motivation	6
Vanilla ERP	6
Project management	6
Troubleshooting/crises management	6
Legacy system consideration	5
Data conversion and integrity	5
System testing	5
Client consultation	4
Project cost planning and management	4
Build a business case	3
Empowered decision makers	3

Figure 11: Number of citations per CSF category (Finney & Corbett, 2007)

Finney & Corbett (2007) conducted research on citations and the tactical and strategic success factors. The classification used by Nah & Delgado (2006) can also be described by strategic success factors, which are supplemented by tactical success factors. The seven main categories and sub categories (Nah & Delgado, 2006):

1. Business plan and vision
2. Change management
3. Communication
4. ERP team composition, skills and compensation
5. Management support and championship
6. Project management
7. System analysis, selection and technical implementation.

In Nah & Degado (2006), we can find several Critical Success Factors. The focus of the study is on the importance of the CSF in different stages of ERP implementation and upgrade projects. These different stages in the ERP implementation are based on a few case studies, the type of thesis which Finney & Corbett analyzed for their research. The identified stages in the implementation of an ERP system are the chartering phase, project phase, shakedown phase and onward & upward phase.

These four stages combine towards the life cycle of an ERP implementation. In the first phase, chartering, the focus lies with identifying the solutions constraints and the business case that is used in the project. During the second stage, the project phase, the implementation is executed. This includes systems tests, user training, system configuration and system integration with other systems in the corporation. The shakedown phase starts just after the launch of the new system and is in order until the ERP runs smooth. Shakedown represents bug fixes, improving the performance and possible retraining of employees. The last stage is the normal use, which includes maintenance and performance improvement.

According to Nah & Delgado (2006), the most important success factor is 'ERP team composition, Skills and Compensation' followed by 'Top Management Support and Championship'. 'Communication', 'Change Management' and 'Project Management' are the next three factors, concluded with the factors 'Systems analysis, Selection and Technical Implementation' and 'Business Plan and Vision'. The overview of Nah & Delgado can be found in appendix K, with the categorization of Critical Success Factors.

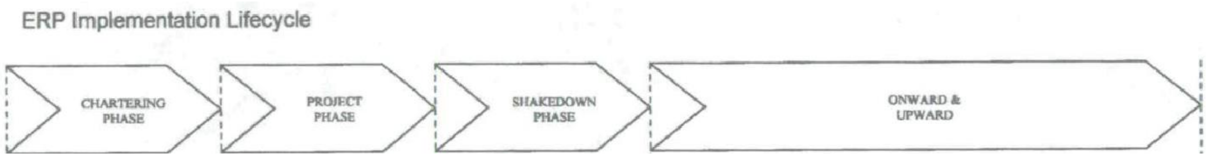

Figure 12: Implementation lifecycle (Nah & Delgado, 2006)

Motwani (Motwani, Subramanian, & Gopalakrishna, 2005) discusses four case studies to identify the Critical Success Factors for a successful ERP implementation. The paper also discusses the importance of change theory in the implementation of the ERP systems and several of the key factors mentioned in Nah & Delgado (2006) and Finney & Corbett (2007).

Motwani et al. (2005) also offers a framework for the successful implementation of ERP software. In figure 13, we see the CSFs according to Motwani et al. (2005) in process view. These CSFs are based on the theoretical framework in appendix L. The proposed theoretical framework is the basis for every ERP outcome, positive of negative. The culture and environment are factors with influence on the ERP outcome. From this framework, we can conclude that some ERP implementations will fail before they have begun. This can be deduced through a negative change environment, reducing the change on successful ERP implementation management and a positive ERP outcome.

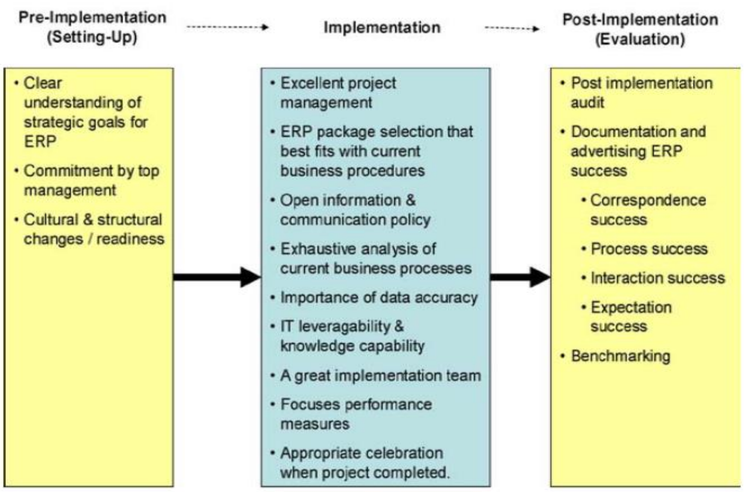

Figure 13 : Implementation lifecycle (Motwani et al., 2005)

Where Nah & Delgado (2006) identify four stages, Motwani et al. (2005) identifies three stages as their proposed process theory: Pre-Implementation, Implementation and Post-Implementation. In comparison with Nah & Delgado (2006), the process theory is almost the same; Motwani excludes the normal usage, maintenance and performance adjustment in the process of implementation but the first three stages are similar in use and meaning.

The proposed CSFs of Motwani (2005), in figure 13, are in alignment with the seven constructs illustrated in the framework from (Al-Mashari, Al-Mudimig, & Zairi, 2003) in appendix M. These are the basis for the total corporate culture, of which the ERP implementation and the result of the implementation are components.

In the case study of Motwani (2005) companies viewed the adoption of ERP as an opportunity for comprehensive Business Process Reengineering. The composition of the project team is also a crucial factor. The team should be representatives of the different company functions and convey a strong will. The commitment of top management to the project is a recurring theme in literature about ERP implementation and Motwani (2005) underlines the need for public and explicit support from top management.

7.5 CSF framework

If we want to use the Critical Success Factors that were evaluated and discussed in the previous section, we need to specify the need of the company.

In the Current Situation of Q&R and Test Engineering we concluded that there was a different business process in the departments. The current situation at Company X is as if there never was a merge between Place S and Place y. The focus of the Critical Success Factors should be on the process of incorporating every part of Company X, to empower the corporate identity, as well as obtaining a unified view for management (Parr & Shanks, 2000) and breaking down information silos that still remain in the company. The silo structure is typical for the culture at Company X, due to the high technicality of the production process and the hierarchical layers of technicians and management that go along with it. The same goes for the process engineering of the Q&R department. The difference in process from Test Engineering is an issue of concern when implementing the ERP system. This should be one of the areas an engineer of Q&R should deliver input in deciding on the ERP system and its possibilities.

If we are to look for the Critical Success Factors that are the most influential for a company like Company X, then we should keep in mind that Company X is a high tech company. Company X has different production processes on the work floor, varying between the departments. It still feels the cultural differences of the merger from 2008 and the employees have a long term work relation of several years.

7.6 CSF for implementing ERP at Company X

Taken into account the chapters on the “Current Situation” in both TE and Q&R, as well as the culture at Company X, we should compose the relevant Critical Success Factors.

Combining the case studies on CSF and the relevant information on Company X, we come to the following framework, with the Critical Success Factors for implementing an ERP system at Company X:

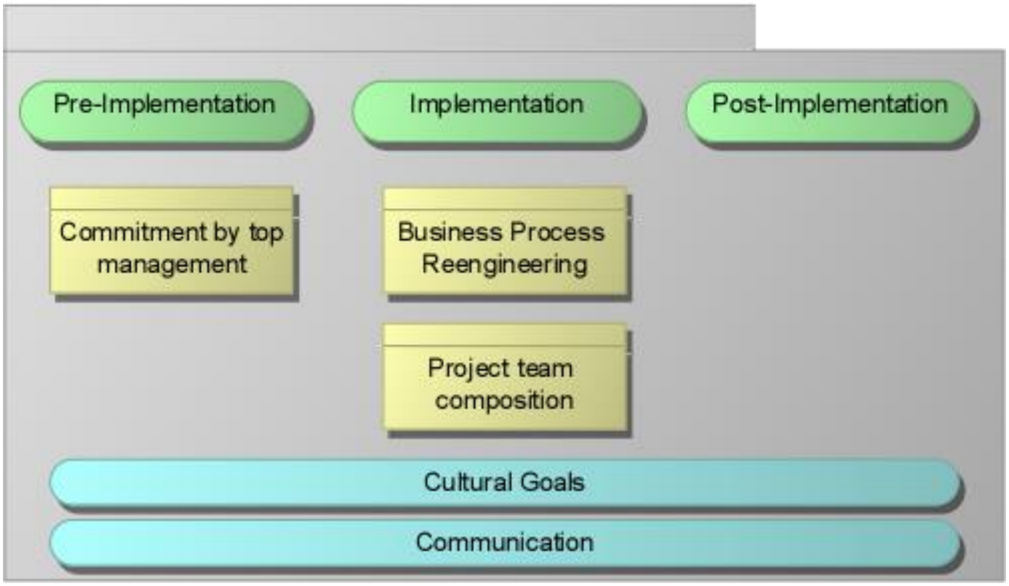

Figure 14: A framework for ERP implementation at Company X

The change environment as seen in appendix L is not optimal in this type of company. The high tech, slow change nature of the business. The learning capacity and cultural readiness in SMBs make the process of implementing ERP difficult (Kettinger & Grover, 1995). The above framework should combine these factors as the most important factors to acknowledge and include while implementing an ERP system at Company X, or at any other high tech SMB with a low acceptance to change. In the following section, we will discuss the framework.

Commitment by top management

The need for commitment of top management to the process is based on an age old principle. It is leading by example. If top management is not committed to implementation, it is hard for employees to be committed. If top management shows the way in the implementation, employees will be more likely to follow. The process itself is described by several scientists; an interesting take is that of McCrimmon. (McCrimmon, 2012) In short, it is stated that leading by example works as a one-way influencing process in which leadership is obtained when the company freely follows the chosen path. This can be done by spreading a vision or by taking action.

Business Process Reengineering (BPR)

In most of the case studies, BPR is an important part of the implementation of ERP. ERP combines the business processes, thus rethinking the process becomes part of implementing the ERP system. In the case of Company X, the production departments even differ in process, so aligning those production processes, as well as incorporating them in the rest of the business modules, will be a vital part of the future success of the company. It not only allows advantages in the worker rotation, due to the fact that the process on the production floor is the same, but also offers extra speed in the scheduling and planning part of the production. Due to the fact that the planning and scheduling of orders is an issue at Company X, the transparency acquired with an enterprise wide planning provides management with information about the production process otherwise unknown.

Project Team

As indicated in the case studies, a project team is the team implementing the ERP system. Employees from different departments are grouped to involve knowledge of their respective department. Next to the specific knowledge, they are also the assigned persons who will provide support in their business unit. Involving respected employees from different departments with leadership qualities is a step in ERP implementation which makes or breaks the implementation. At Company X, the departments are a class example of the 'we vs. them' culture. This culture empowers the need for a strong ERP implementation team, with highly respected representatives from each department.

7.7 A general view of CSFs in high tech SMBs

The framework above is especially designed for Company X. It is to be noted that there are more CSFs which can be of influence, but the above are specifically important to Company X due to the nature of the company and the corporate culture. Taking the parameters from Company X, we can also make a more general overview of the CSF in high tech SMBs. We will use the case studies mentioned before and the CSFs in the literary studies to build the framework, just like we did with Company X:

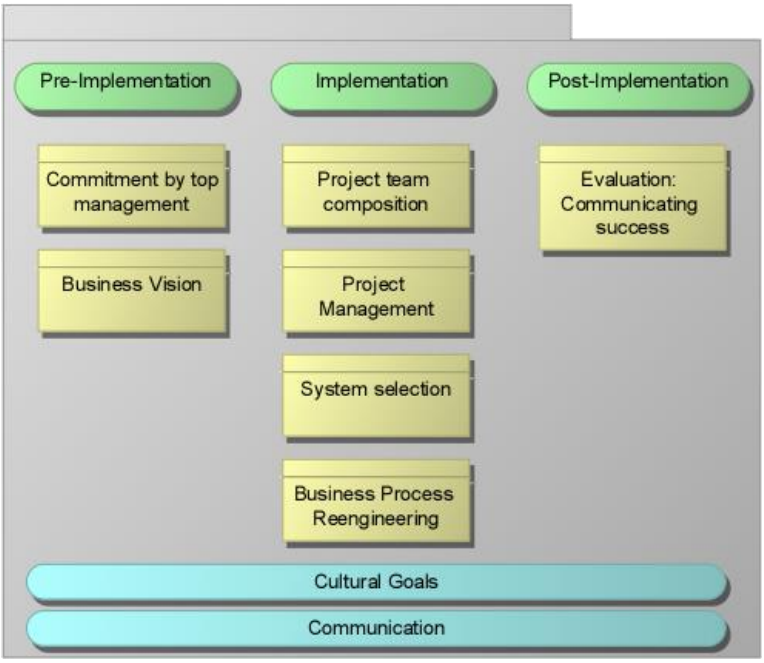

Figure 15: A framework for ERP implementation in a high tech SMB

Pre-implementation

In the pre-implementation phase, the commitment of top management and a clear business plan and vision are the critical success factors. Commitment by top management is done by openly announcing their efforts to make the implementation a success. Approving the process and allocating the resources to the implementation are important aspects for top management. A clear business plan with a defined mission helps the process. Having a clear goal in every process prevents the purposeless progression in that process. This also goes for the implementation process for ERP systems. Communicating these aspects improve the acceptance of employees for the need of the investment.

Implementation
Four success factors have to be taken into account during the implementation, next to the communication and the corporate and cultural goals. The project team needs to consist of respected team members from the departments, able to persuade gatekeepers in their own department. The project management is the execution of the implementation. It includes the discipline of motivating, planning, organizing and controlling resources towards the goals set in the pre-implementation. The system selection should be in line with the corporate culture and serve the business processes. The system selection has to be done coherently with the reengineering of the business processes, analysing the workflows and processes within an organization. The process of implementing an ERP system can help to rethink how the work is done in the company.

Post-Implementation
The last part of a successful implementation is a companywide evaluation of the implementation. The evaluation should go into depth on the interaction, the level of success in the implementation process and the expectations of the system. The results should be shared throughout the company, promoting the success of the implementation. During the whole process, the communication and corporate goals should be a constant factor. The corporate goals help to align the employees and increase the feeling of coherence, making the project management and process reengineering easier. Lack of communication is a downfall for the whole project. Constant updates on timeliness, progress and success of the process adds to the transparency of the process to outsiders and gatekeepers that otherwise might feel neglected or excluded.

7.8 Conclusion

The implementation of an ERP system offers several possibilities for the company. It gives the opportunity to rethink the business processes, as well as building a better corporate mind set. The possible negative side of an ERP implementation is that the costs, in resources as money and man hours are very high. The chance exists that the implementation fails, or only works out partially. The implementation process is a lengthy one. ERP software fails if the company did not dedicate enough time or money to training and managing culture-change issues (Gale, 2002). Literature gives us several Critical Success Factors for the implementation which are confirmed in the case studies. The proposed CSFs are business wide, for the more typical high tech small and medium businesses, we introduced a more specific CSF module, focusing on the culture in that type of companies.

8. Integrating Qualification and Reliability

In the previous chapters, we looked at the business process of Company X Place y and we researched the CSFs that influence an ERP implementation. In this chapter, we combine the two parts represented in this paper to be able to write steps to integrate the Q&R department in the rest of the production facility. We use the comparison from chapter 6 and the theory from chapter 7 as the basis for the road map for integrating Q&R.

8.1 Comparison TE and Q&R

At the end of chapter 6, we compare the production departments of Test Engineering and Qualification and Reliability. The overview is given in table 3. As noted earlier, the machinery varies in the two departments. The current planning and scheduling in the departments also differ. The responsibilities from the employees in both departments are similar. The difference in machinery demands that the technicians and engineers have in depth knowledge about the machinery to maintain or repair the machines, or to design new tests for ICs.

	Department	
Variables	**Qualification & Reliability**	**Test Engineering**
Machinery	- High variety - Long test times per IC - Small batches	- Low variety - Short test times per IC - Large batches
Operator (**Employees**)	- Loading and unloading boards - Loading and unloading machines - Signalling errors	- Loading and unloading machines - Signalling errors
Technician (**Employees**)	- Maintenance - Repair	- Maintenance - Repair
Engineer (**Employees**)	- Customer contact - Designer of tests - Responsible	- Customer contact - Designer of tests - Responsible
Planning	- Manually in Excel	- Schedule from ERP module PPS

Table 3: Deparments compared

8.2 ERP framework

In chapter 7, we have laid the literary framework to implement an ERP system. In the cases we studied, CSFs were the basis on which an implementation project would fail or succeed. For the purpose of Company X, we modelled the CSFs to make it fit the needs of a high tech, small to medium business. This model is shown in figure 16. It encompasses three stages, pre-implementation, implementation and post-implementation. Communication and cultural goals in the company are success factors throughout the process. Commitment by top management is especially important during pre-implementation. The implementation at Company X asks for a Business Process Reengineering and is critical towards the composition of the project team. Company X has no defined CSFs during the post-implementation phase. Communicating and evaluating the cultural goals inside the company should be the focus during post-implementation, the two factors which are important throughout the process.

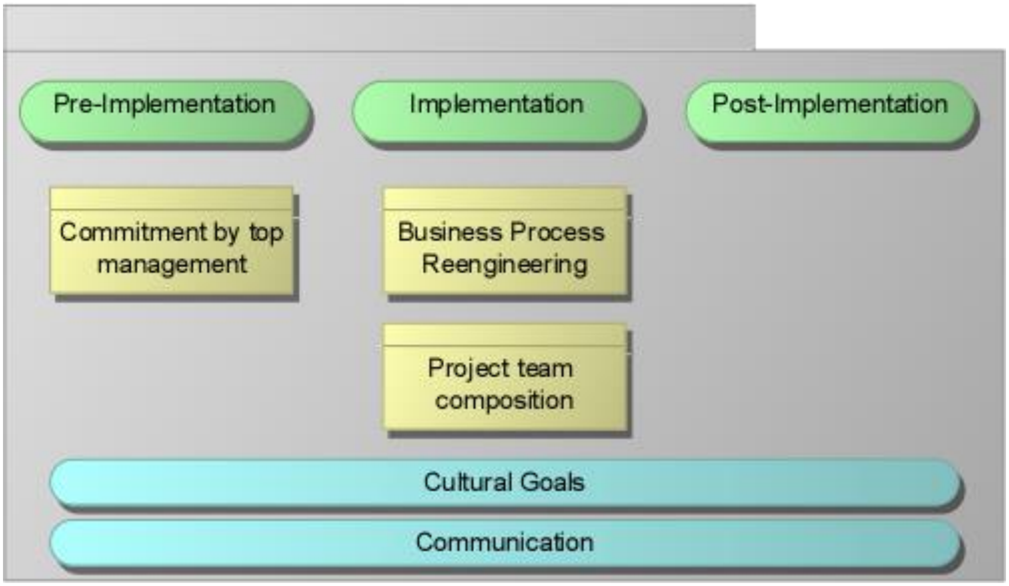

Figure 16: Critical Succes Factors Company X

8.3 The integration road map

In 7.1 we identified a problem concerning the corporate culture of Company X. While this is not the main issue of this thesis, it is one of the causes for our main research question. We take the comparison between the two departments from table 3 and the framework for CSFs as shown in figure 16 as a basis for the road map of the upcoming changes.

There are several possibilities to achieve integration between the Q&R department and the rest of the production departments. The first suggestion in the process of integration is pooling of employees. The 'Operators' in the department do similar work and can be pooled. Pooling is a part of resource management that maximizes advantage or minimizes risk by grouping resources together, in this case Operators. Combining the descriptions of chapter 4, 5 and 6 on Operators, we come to the following skill set for the employees currently at Company X in Table 4. In Appendix N the skills per employee are shown. For privacy issues, the operators are listed under an anonymous title in Appendix N and the majority of the operators from the departments are included in the table. From Appendix N and table 4 we can take that with minor training, it is possible to combine the operators on skill level.

	Departments	
	Qualification & Reliability	*Test Engineering*
Skills		
Manual Electrical Test	x	x
Sensitivity Test	x	
Packaging	x	x
Loading / unloading machinery	x	x

Loading / unloading Burn In Boards	x	
Visual Incoming Inspection	x	x
Fine Leak / Gross Leak Test	x	
Controlling Q&R Test (HTOL, THB)	x	
Controlling TE Test (Failure ID, Jam prevention)		x

Table 4: Operator Skills per Department

The second suggestion for the integration is to start with returning social events. A good example of this type of events is an end of the month gathering with some drinks for all the employees.

The third suggestion for the integration is the combining of the planning and scheduling. For TE, this planning is done via the ERP planning module. The ERP implementation is the next step. The implementation process is done via the CSFs of figure 16. This is summed up as follows:

Pre-implementation

- *Top management commitment*: the board of directors, the management team and the board of commissioners of Company X are to setup a forum or gathering for all the employees to introduce the plans. Every member of top management is to speak up and openly declare their commitment to the upcoming plans and answer questions from their employees.
- *Cultural goals*: The cultural goals are part of the communication during the gathering. This is boiled down to the 'Why' question of Simon Sinek (Sinek, 2010). The internal goal of one corporate identity is to fade out the 'us vs. them' culture.
- *Communication*: The forum is a starting point for top management to communicate their commitment towards the project. This positive attitude about the process is expected from every member of top management throughout the project.

Implementation

- *Project Team Composition:* The project team for the ERP implementation is to consist of one gatekeeper from Q&R and one gatekeeper from TE, preferably technicians. The rest of the team is to be selected from the sales department, the planning and work preparation department and the top management. This is only the Company X Place y delegation. We have no information regarding other facilities such as Place S or Place D. To keep the project team members to a minimum, they are excluded for the further process and their interests are defended by the member from top management.
- *Business Process Reengineering:* The process at Q&R is revised. The excel sheets are excluded from the new business process. The needs from Q&R have to be mapped and fulfilled in the ERP system, especially for the planning module. To serve all their customers, extensive reports regarding the qualification tests are required from the ERP system. Every variable that should be available for Q&R is included in the ERP system.
- *Cultural goals:* Reiterating the goals the company strives towards. A bottom up approach with feedback and room for discussion allows the employees to make the body of thought their own and adopt it. The discussion is to be done throughout the whole company. An example is to go on a company retreat and brainstorm for a few days to rethink the cultural goals that were communicated by top management.
- *Communication*: Progress in the composing of the project team and in the BPR process is communicated throughout the company. For Company X, this can be done via the billboards, via internal mail or via the informal end of the month drinks.

Post-implementation

- *Cultural goals:* Every employee has a clear understanding of the mission statement of the company and why Company X does the things they do.
- *Communication:* Communicating progress includes communicating the end of business process reengineering. Evaluating the process and communicating the successes of the implementation as well as being open about failures improves the total ERP implementation.

The fourth suggestion is to pool technicians. This can be done when the planning of the TE and Q&R department is incorporated in the ERP system. It does require more in depth knowledge from technicians about the machinery from the other department. This in depth knowledge is attained through training, both inside the company from other technicians and externally.

The fifth suggestion is to fully integrate the production floor of Company X Place y. Physically, as we can see in appendix C, the production floor is already integrated. This full integration means the engineers can combine their knowledge. It is dependent on the success of the pooling of technicians and Company X needs a strong corporate culture to allow this change.

8.4 Conclusion

There are several possibilities to integrate the Q&R department into the rest of the company. The effect of the suggestions provided in this chapter may vary; we believe every single one of them will have a positive effect, now or in the future. The feasibility study and the literary study show the possibilities for the integration of the Q&R department. The suggestions integrate the employees of the Q&R department from the bottom to top and integrate the planning in the ERP system to allow automated test plans. The first three suggestions start relatively fast, the remaining two are based on the success of the first three. The suggestions are as follows:

- Pooling operators from Q&R and TE
- Regular social activities
- Implementation of the ERP system
- Pooling Technicians
- Integrating TE & Q&R

Executing these suggestions leads to a stronger corporate culture and identity.

9. Conclusion and recommendations

In this research, we have looked at Company X, a test house situated in Germany and the Netherlands for optic- and microelectronics with customers all over Europe. Due to changes in the market, Company X has to improve their business sense, a challenging task in a small and high tech company.

Before we can answer our main research question in order to achieve the goal of the research, we will review our sub questions and walk through the research.

9.1 The Current situation

The two main production divisions are “Qualification and Reliability” and “Test Engineering”. The Test Engineering department operates bulk quantities, due to the fact that the extensive testing has already been done. The Integrated Circuits (IC) that are processed are ready for end use if the testing is completed. The Test Engineering focuses on one defect at a time, processing the ICs sequential with a test time of several seconds.

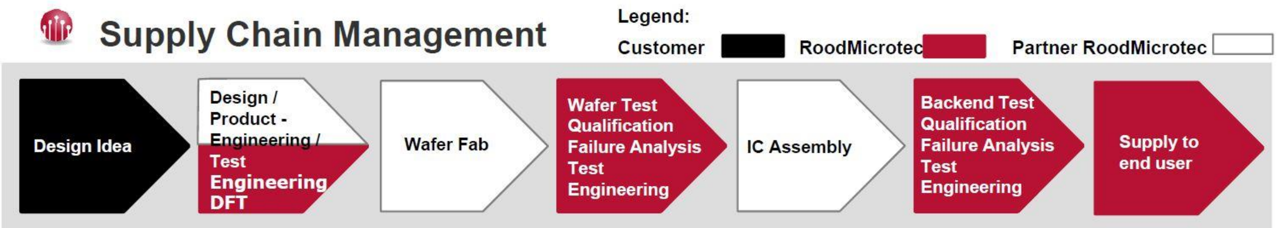

Figure 17: Supply Chain ICs

At Qualification, as we can see in figure 16, the tests are done before the IC is assembled. The testing is more extensive and is used to map all the properties of the ICs. This extensive process is about low quantities and a long testing time, often destroying the circuits to obtain every bit of useful information.

Processes and machinery

The process at Test Engineering is pretty straight forward, with only three types of tests which can be adjusted at machine level. At Qualification, the amount of different test chambers is significant. The list of possible tests is shown in appendix E. Due to a higher variety in machinery the Q&R department is facing idle machinery more often. Next to that, the possibility of adjusting the machinery for different sets or types of ICs is available to the machines in TE but not in Q&R, increasing the likelihood of an idle machine and bottleneck machinery.

Employees

The types of employees used in both Q&R and TE are the same, the in depth knowledge differs between the departments. The knowledge needed to repair or adjust certain machines is increased at the Q&R department due to a higher variety in machinery. The possibility to exchange employees between the departments should be available. Currently, differences in culture make it hard to interchange employees between the departments. Operators can be pooled easier than technicians based on the skills needed on the production floor. Technician can, in turn, be pooled easier than the engineers, who are responsible for the department. Pooling employees does require clear working arrangements in terms of hierarchy and responsibilities towards each department.

Planning

At both TE and Q&R, the process of planning the work is regulated. At TE, the current ERP system is used to forecast the need of certain products and use the up to date information from the production floor to schedule the production for the day or the following week. At Q&R, the planning process is based on an Excel sheet, which is updated manually. This process is time intensive and used next to the ERP test plans which are also produced. The amount of detail available in Excel is the reason the department of Q&R uses it to schedule and plan machinery. The planning from Excel, together with the manual updates is part of the shipment to the customer, the high variety made it difficult to incorporate all the Q&R processes in the ERP system.

9.2 The ERP system

At the time of the research, the data system that was in place is called Oxaion. This ERP system worked for the TE department, the Q&R department claimed that the adjustability of the test plans was not sufficient for the needs of their customers. The amount of information a customer from Q&R needs is more due to the design process. After interviewing employees on the Q&R department, it became clear that it is possible to incorporate the Q&R process in the ERP system, but that it will be time intensive. This change needs to be supported and therefore we identified the critical success factors for the implementation of an ERP system.

From the case studies, we concluded that the traditional, high tech, small business, like Company X, is a slow respondent to change. The higher goal is not to implement the ERP system itself, but a means to obtain an efficient business and production process. To achieve this goal, the ERP system combines all the business units into adaptable management information on every level. An example would be of the sales clerk who can already forecast the delivery date of the product due. The ERP system can take the total production time with the current setup and breakdown rates in account and make a forecast based on real time data.

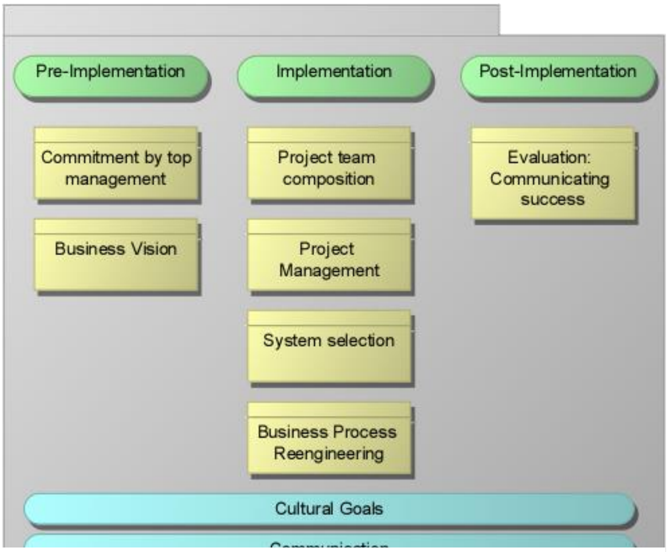

Figure 18: ERP implementation CSFs in high tech SMBs

Every phase of the implementation process has a focus point in the success of the ERP system.

In the pre-implementation phase these are:

1. *Commitment by top management:* Often and loud, management should devote their leadership qualities to persuade the gatekeepers in the organization to accept the upcoming change. Allocation of resources towards the project is an effective way to follow up the words with action.
2. *Business Vision:* The reason to start with something, actually defining it, helps the believability of what your business is trying to achieve (Sinek, 2010).

During the implementation, the aspects that we just identified are still of importance. Other success factors are included:

1. *Project team composition:* Due to the high amounts of hierarchy and reluctance to change, the team composition is vital in communicating the upcoming changes and providing support in the company for these changes.
2. *Project management:* Clear directions and an overview of the changes are given by the project management team. It is the natural follow up to the business vision of the pre-implementation phase.
3. *System selection*: ERP systems vary a lot. While it is in most cases ideal to have a custom ERP system, this is hardly affordable in a SMB. The right consulting of the needs throughout the company is essential for the attitude employees have towards the system and change. In general, employees need to have the feeling that they have been acknowledged in the process.
4. *Business Process reengineering:* At Company X, reviewing the business process for the Q&R department, especially for the planning and scheduling, should be done during the implementation. The Excel test plans should be discarded and the scheduling is to be incorporated in the ERP system, with the level of detail that is needed.

Taken into account the above factors, the top management could have a very successful implementation on their hands. In the post implementation, there is one success factor left to assure the acceptance of the implementation:

1. *Communicating success*: The evaluation should go into depth on the level of success in the implementation process and the expectations of the system. The results should be shared throughout the company, promoting the success of the implementation.

During every part of the implementation process there are two aspects which influence the success of the implementation:

1. *Cultural goals*: The business vision and the project management both take this point into account, but throughout the implementation process the cultural goals should be repeated often in the company. The cultural goals are a sub set of the 'Why' question, which should be the motivator for the company and the basis for the corporate identity.
2. *Communication*: As for every company, communication is the start and the solution to every problem. Throughout the process, companywide communication should improve acceptance in the post implementation stage and improve information sharing.

9.3 Integrating Q&R

The integration of Q&R into the rest of the facility in Place y is the result of the literary and feasibility study performed at Company X. The road map for this integration is:

- Pooling operators from Q&R and TE
- Regular social activities
- Implementation of the ERP system
- Pooling Technicians
- Integrating TE & Q&R

The tasks of operators are similar in Q&R and TE. They can be combined to maximize the efficiency of the resource labor. Regular social activities improve the corporate feeling, for example end of the month drinks or team building exercises. The implementation of the ERP system allows the planning and scheduling to synchronize for both TE and Q&R. This opens up the possibility to pool the technicians in the future. The last difference between the two departments in the long run is the difference in machinery. Dependent on the success of pooling technicians, the integration of both production departments can be carried out. This eliminates an engineer and combines the whole production floor of Place y into one production department.

9.4 Insight in the current business process of Company X

The purpose of this research is to provide Company X with insight in the current production and planning process as well as the use of capital, both through labour force and machinery, in the areas of Test and Qualification & Reliability.

Now, if we look back at our main research question:

> **"In what way, given the current available machinery, employee database and culture at Company X, can the department of Qualification & Reliability be integrated in the production floor?"**

The problem is defined by the difficult production process of the Q&R department. This production process influenced the employees of the Q&R department in their thinking patterns, allowing them to enter a paradigm in which cooperation with the TE department was not possible. The implementation of a new ERP system could provide the means towards a corporate identity for Company X, incorporating all business functions in the ERP system. The CSFs provided in this thesis should be taken into account when implementing the ERP system, creating a favourable environment in which the employees can flourish.

9.4 Recommendations for further research:

In this research we have created an insight in the possibilities to exchange employees between both Q&R and the rest of the production process, especially TE. Now it is necessary for Company X to optimize the workforce in the production department by combining the TE and Q&R employee database, considering safety regulations.

After the new ERP system has been installed and the production departments are integrated, it is much easier to gain insight in the production costs per item. Comparison between machinery for their usage, production costs and downtime is a vital next step.

After the business process is reengineered, the actual machinery can be taken into account. There is a lot of downtime inside the company because of failures or hasty deliveries. This should be reflected in the pricing of the company, which feels incomplete due to the lack of management information that is available. This encompasses the pre calculated and actual production costs of testing in both Q&R and TE. The process of accepting an order at the sales department is also a very interesting question when the management information is available.

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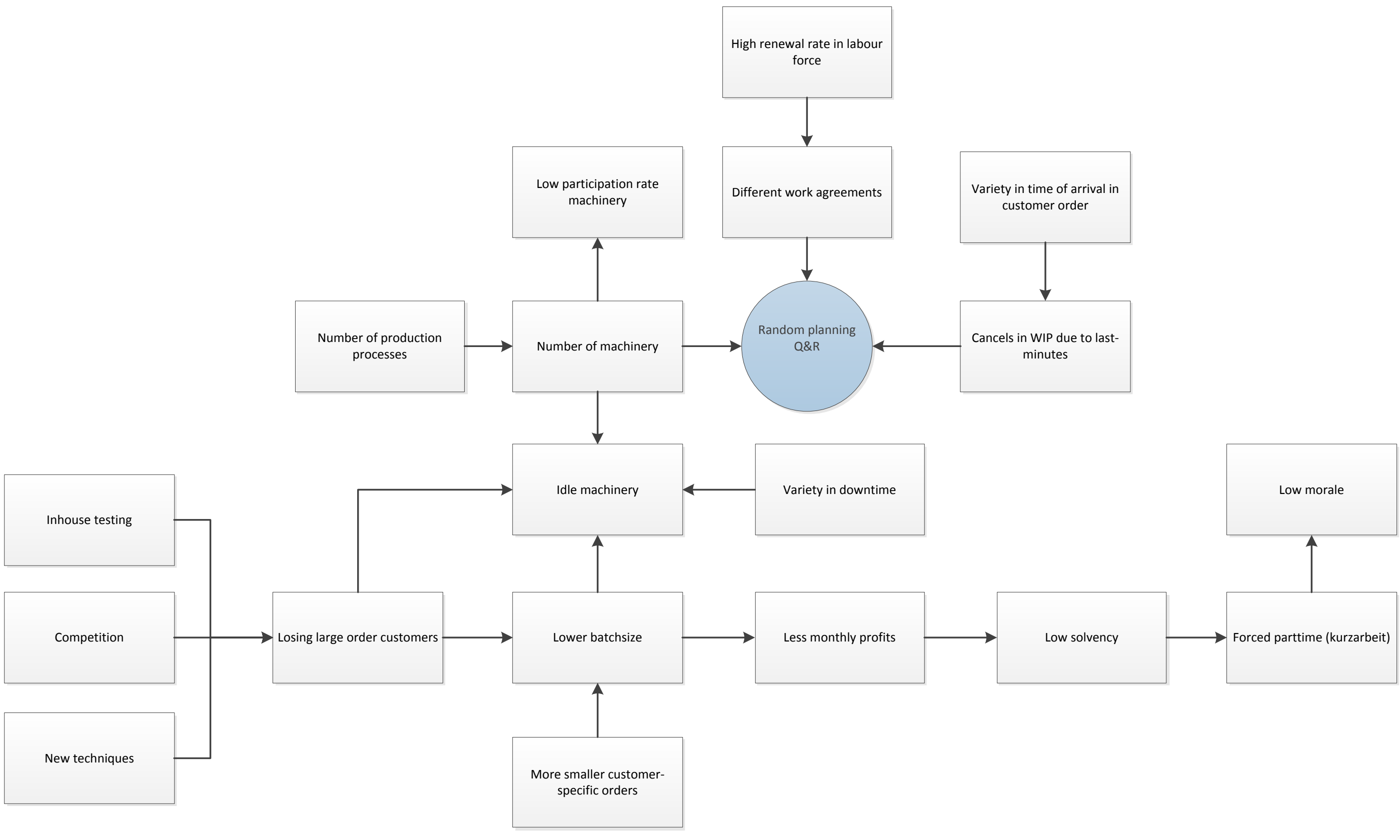
11. Appendices

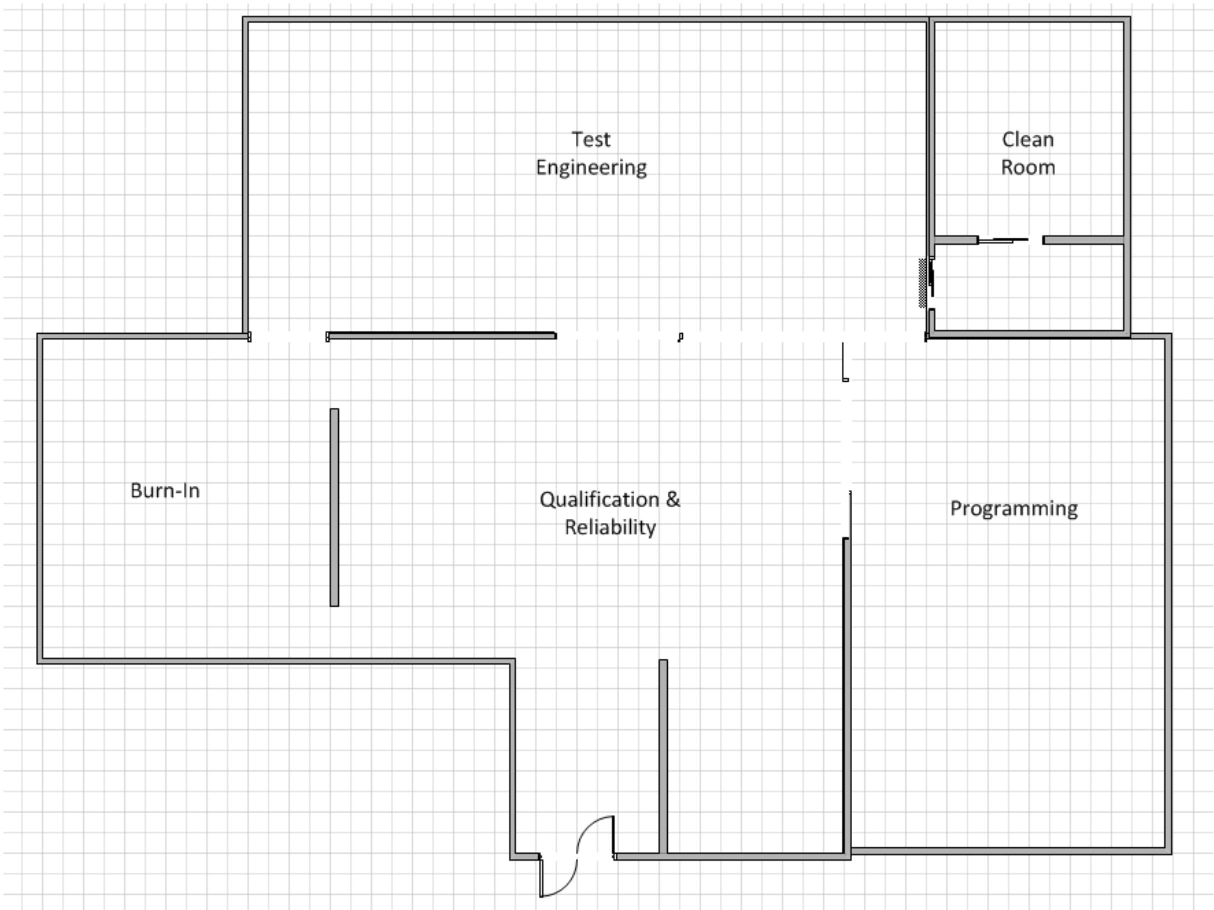
Appendix A: Organizational Chart Company X

Not available in the public version.

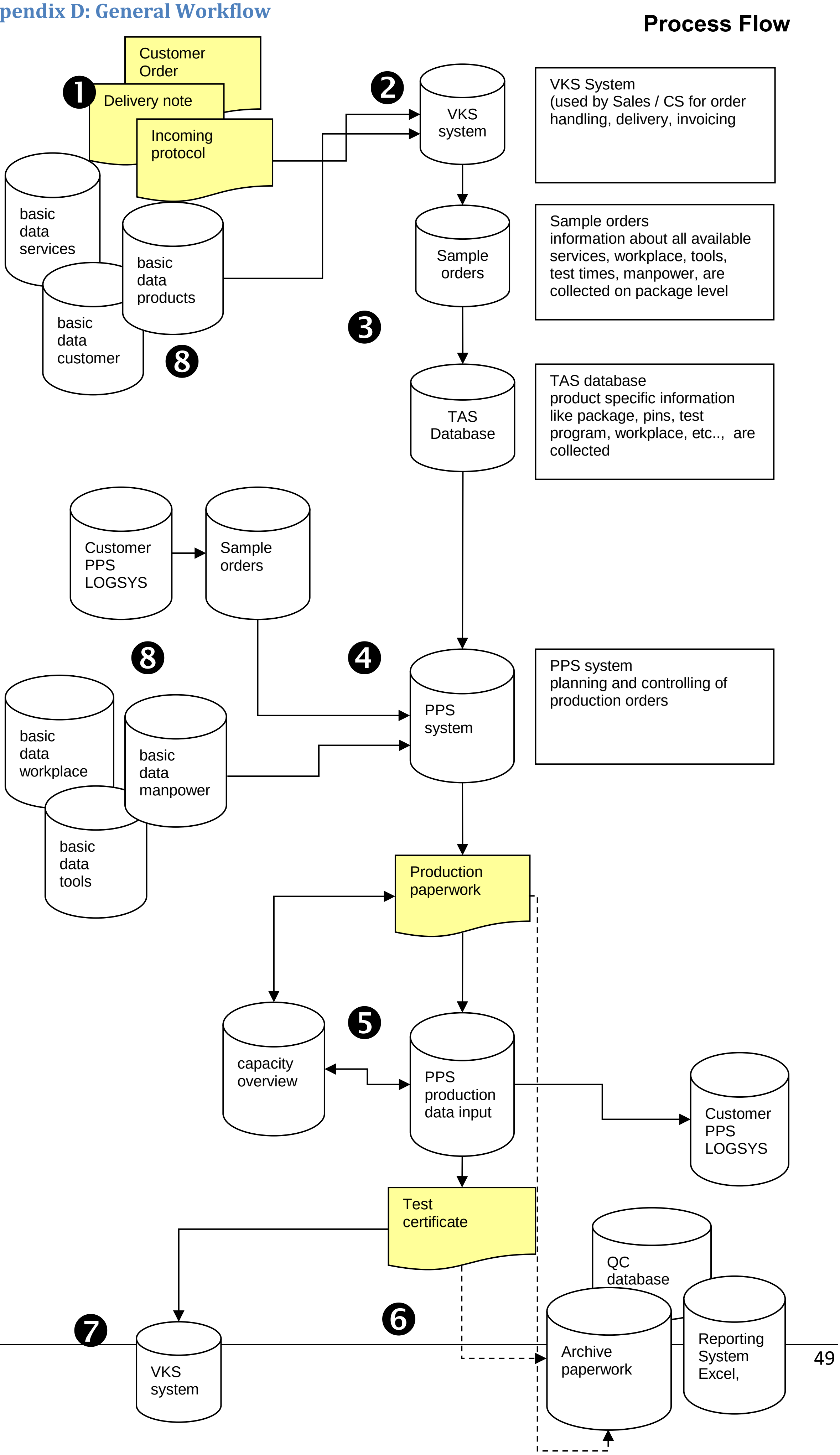
Appendix B: Problem relations Q&R department



Appendix C: The production floor, Place y, Germany



Appendix D: General Workflow



Appendix E: List of Test Chambers

Temperaturprüfungen:

Type	Model	KB	Inventar-#	Serien-#	Kennwerte
Temp. Kammer	UT6120	TK2	RTD-ET.001	9003407	T= +25°C – +200°C

Stresssysteme:

Type	Model	KB	Inventar-#	Serien-#	Kennwerte
IOL	IOL Hora	IOL1	6562080	1-0104	△ Tj= 75 – 175°C IDS <= 12,5A VDS<= 12V 3 Gruppen
IOL	IOL Hora	IOL3	6001127	1-0602	△ Tj= 75 – 175°C IDS <= 12,5A VDS<= 12V 3 Gruppen
IOL	IOL Hora	IOL4	6001166	1-0603	△ Tj= 75 – 175°C IDS <= 12,5A VDS<= 12V 3 Gruppen
HTRB/HTGS	HTRB/HTGS Hora	HTRB2	6001129	1-0106	T= 50 °C – 200 °C VDS= –1200V – +1200V VGS= -60V - +60V
HTRB/HTGS	HTRB/HTGS Hora	HTRB3	6001130	1-0306	T= 50 °C – 200 °C VDS= -1200V – +1200V VGS= -60V – +60V
HTOL	Vötsch VTU60-90	TU4	6001169	6130010	T= 50 °C – 175 °C
HTOL	Vötsch VTU60-90	TU5	6001170	6130020	T= 50 °C – 175 °C
HTOL	Vötsch VTU60-90	TU6	6001171	6130030	T= 50 °C – 175 °C
HTOL	Vötsch VTU60-90	TU7	6001172	6130040	T= 50 °C – 175 °C
HTOL	VMUB02/13/250	TU1	3503100	23434	T= 85°C V= 0-50 V I= 0–100 A 24 Slots
HTOL	VMUB02/13/250	Murr	210/016 (RMS)	26287	T= 85°C- 125°C V= 0-50 V I= 0–100 A 24 Slots
PTC	Espec TSA-201S-W	PTC1	6001105	15300 2427	T= -40°C-+85°C V= 5-35 V I=0-100 A 18 Slots

Type	Model	KB	Inventar-#	Serien-#	Kennwerte
PTC	TSA-201S-W	PTC2	6001128	15300 2643	T= -40°C-+85°C V= 5-35 V I=0-100 A 18 Slots
H3TRB	PL-2KPH	H3TRB1	6001167	140	T= 85°C

		RTN		15093	RH=85% V= 0-300V I= 0-450 mA
H3TRB	PL-2KPH	H3TRB2 RTN	6001168	140 15086	T= 85°C RH=85% V= 0-300V I= 0-450 mA
THB	Espec PR-4KTH	THB1	6001103	SN14013 944	T= 85°C RH= 85% V= 0-250 V I= 0-6000 mA 18 Gruppen
THB	Espec PR-4KTH	THB2	6001104	SN14013 955	T= 85°C RH= 85% V= 0-250 V I= 0-6000 mA 18 Gruppen
HTOL	EDA Labline	BI03	6001288	3745	T=50°C – 150°C 8 Slots
Burn In	EDA DA48HD/H	BI01 BI02	6001257	3746	T=50°C – 150°C 2 x 24 Slots

Umweltprüfungen:

Type	Model	KB	Inventar-#	Serien-#	Kennwerte
Temp.Zyklen	VT 7012 S2	TZ3	351970	524/79993	T= -65°C – +185°C
Temp. Zyklen	TSD-100	TZ4	6001229	140000032	T= -65°C – +185°C
Temp. Zyklen	Espec TSA-101 S-W	PTC3	6001230	153003079	T= -70°C –+200°C
Temp. Zyklen	Espec TSA-101 S-W	PTC4	210/139 (RMS)	153002437	T= -70°C –+200°C
Temp. Schock	VFS07/15/2	TS1	3511900	32019	T= -65°C – +165°C
Klima	VCS7057	KP2	3521500	585660135 80010	T= -70°C – +180°C, RH= +10 – +95 %
Klima	VCS7027-15	KP3	3523000	585660608 70010	T = -70°C – +180°C RH=+10 – +95 %
Klima	PL-2KPH	KP4	6001228	14015933	T= -40°C – +180°C
Klima	VC7020	KP6	210/088 (RMS)	552\83461	T = -70°C – +180°C RH=+10 – +95 %
HAST+PCT	EHS-221M	DP2	210/141 (RMS)	133000730	T= +85°C – +130°C, RH= +85 – +100 %

Mechanische Prüfungen:

Type	Model	KB	Inventar-#	Serien-#	Anwendungsbereich
Helium Detektor	UL500	FL	3509200	15585	Leckrate > $2x10^{-10}$mbar*l/s
Zentrifuge	9000	CA	454240	9005-F57	G= 0g - +999.999g
Bubble tester	GL TT1	-	560839	560839	T= +125°C

Appendix F: Management Structure

Not available in the public version.

Appendix G: Test Plan Qualification and Reliability Department

Not available in the public version.

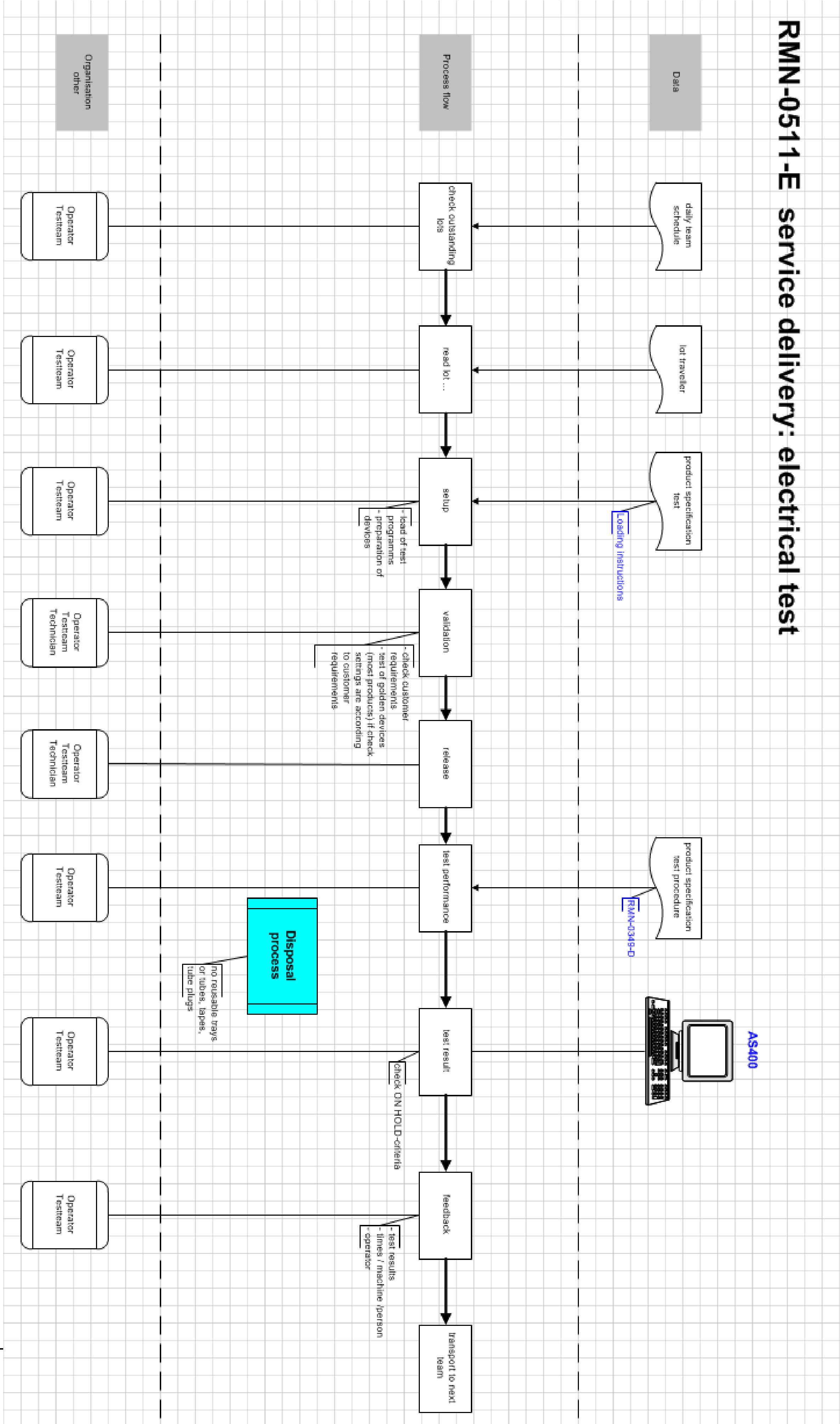
Appendix H: Test Engineering Machinery

H1: Electrical Test machine[6]

H2: Wafer Test Chamber[5]

[5]https://www.evgtshop.com/epages/EVGroup.sf/en_IE/?ObjectPath=/Shops/EVGroup/Products/%22EVG520IS%20Semi-Automated%22&ViewAction=ViewProductDetailImage
[6]http://www.mektra.com/art/mul_8501.jpg

Appendix I: Electical Test Work flow

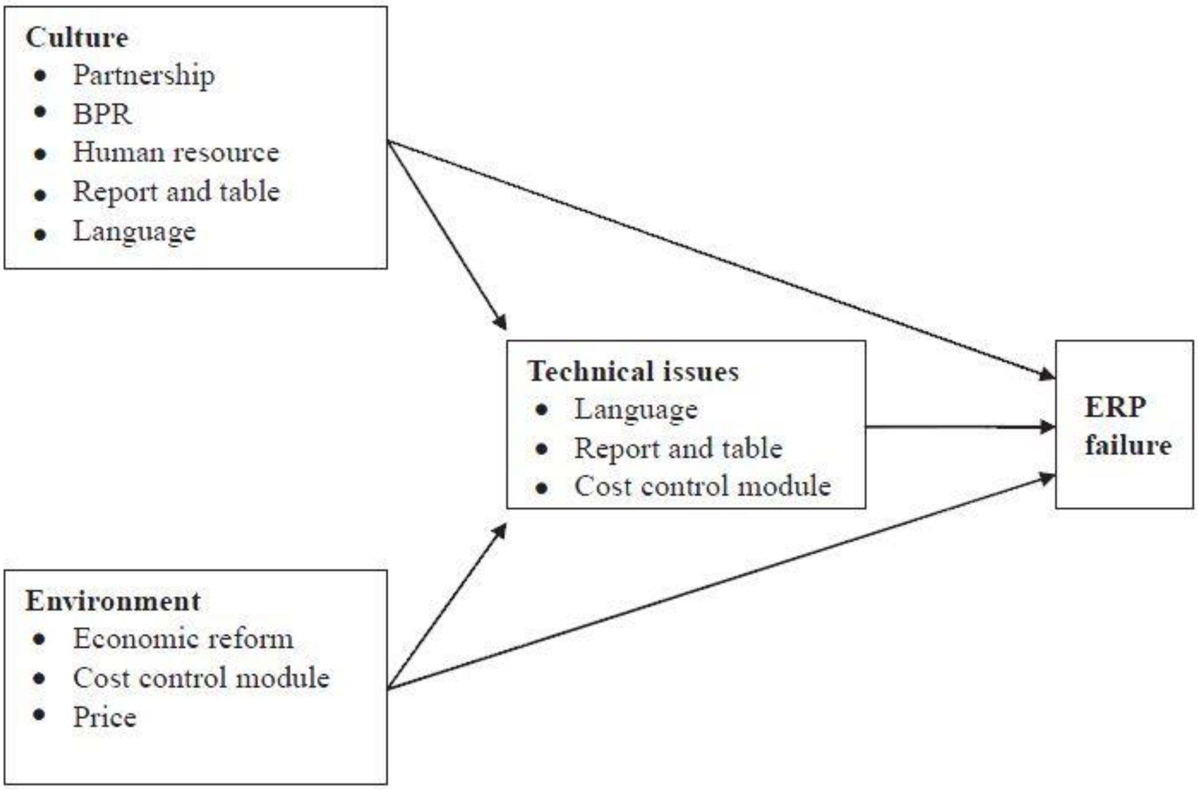


Appendix J: ERP failure factors

Factors affecting ERP implementation failures

	Case 1, CosmeticCo	Case 2, PharmaCo	Case 3, ElectricCo	Case 4, FurnitureCo	Case 5, StoneCo
Language	+				+
Report and table	+				+
BPR	+	+	+		
Economic reform impact			+		
Cost-control module				+	+
Human resource problem	+	+			+
Price issue			+	+	
Partnership	+	+			+

J1: Case studies combined with factors



J2: Causes for ERP failure

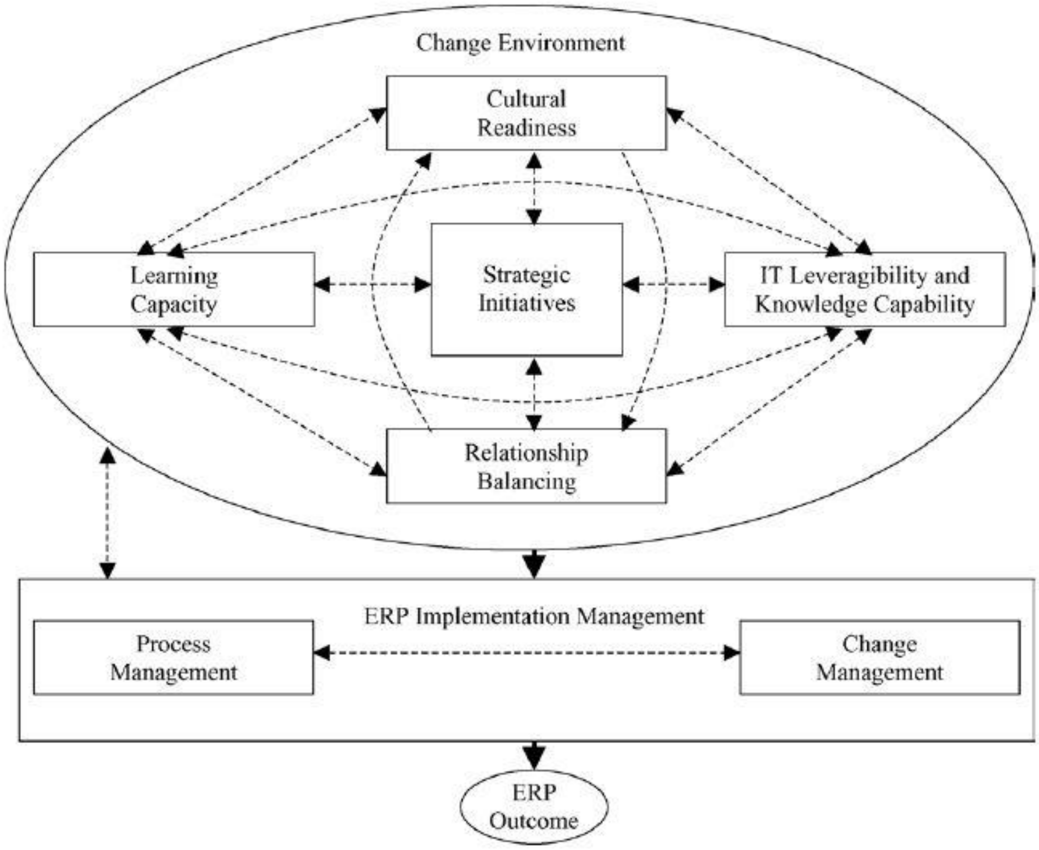
Appendix K: ERP Critical Success Factors

TABLE 1
Categorization of ERP Critical Success Factors

1.	**Business plan and vision** 1.1 Business plan/vision (2, 5, 6, 12, 13, 26, 38) 1.2 Project mission/goals (2, 30, 35) 1.3 Justification for investment in ERP (8)
2.	**Change management** 2.1 Recognizing the need for change (8) 2.2 Enterprise wide culture and structure management (3, 8, 26, 35) 2.3 Commitment to change-perseverance and determination (30) 2.4 Business Process Reengineering (2, 4, 13, 19, 30, 35, 38) 2.5 Analysis of user feedback (2, 13) 2.6 User education and training (2, 3, 4, 13, 19, 30, 35) 2.7 User support organization and involvement (38) 2.8 IT workforce re-skilling (3, 36)
3.	**Communication** 3.1 Targeted and effective communication (2, 8, 35, 38) 3.2 Communication among stakeholders (13, 30) 3.3 Expectations communicated at all levels (13, 26, 30, 35, 36) 3.4 Project progress communication (13, 36)
4.	**ERP team composition, skills and compensation** 4.1 Best people on team (4, 5, 8, 26, 30, 32, 38) 4.2 Balanced or cross-functional team (13, 30, 35, 36) 4.3 Full-time team members (30) 4.4 Partnerships, trust, risk-sharing, and incentives (9, 10, 25, 35, 38) 4.5 Empowered decision makers (30) 4.6 Performance tied to compensation (8) 4.7 Business and technical knowledge of team members and consultants (2, 3, 4, 10, 11, 30, 35, 36)
5.	**Project management** 5.1 Assign responsibility (26) 5.2 Clearly establish project scope (3, 13, 30) 5.3 Control project scope (26, 30, 35) 5.4 Evaluate any proposed change (36, 38) 5.5 Control and assess scope expansion requests (36) 5.6 Define project milestones (2, 3, 13) 5.7 Set realistic milestones and end dates (19, 30) 5.8 Enforce project timeliness (2, 26) 5.9 Coordinate project activities across all affected parties (3, 8) 5.10 Track milestones and targets (2, 19, 26, 35, 36)
6.	**Top management support and championship** 6.1 Approval and support from top management (2, 3, 4, 5, 19, 27, 30, 35, 36) 6.2 Top management publicly and explicitly identified project as top priority (30, 38) 6.3 Allocate resources (2, 3, 13, 30, 35) 6.4 Existence of project champion (30, 35, 36) 6.5 High level executive sponsor as champion (8, 19, 26, 35) 6.6 Project sponsor commitment (26)
7.	**Systems analysis, selection and technical implementation** 7.1 Legacy system (2, 13, 15) 7.2 Minimum customization (3, 16, 19, 26, 30, 35, 36) 7.3 Configuration of overall ERP architecture (38) 7.4 Vigorous and sophisticated testing (2, 26) 7.5 Integration (4, 15, 35) 7.6 Use of vendor's development tools and implementation methodologies (31, 25) 7.7 ERP package selection (2, 3, 14, 23, 33, 34, 35, 37) 7.8 Selection of ERP Architecture (35) 7.9 Selection of data to be converted (35) 7.10 Data conversion (3, 35) 7.11 Appropriate modeling methods/techniques (19, 28) 7.12 Troubleshooting (13)

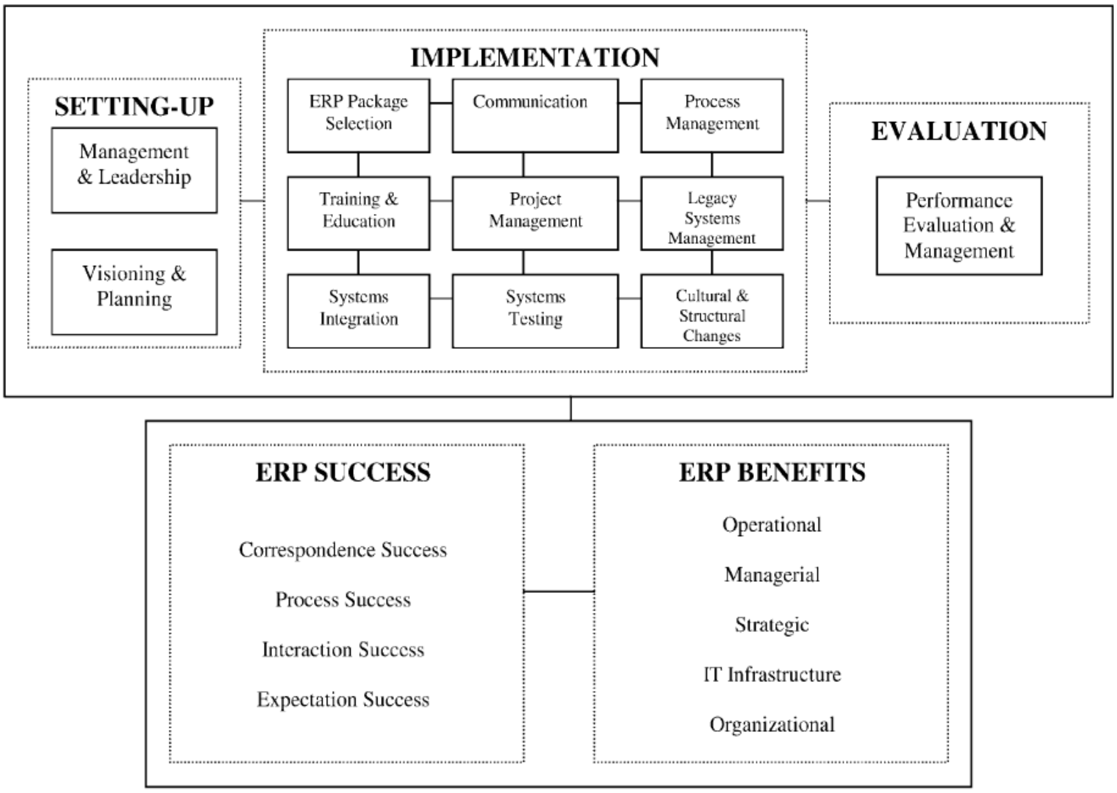
K1: Categorization of ERP CSFs (Nah & Delgado, 2006)

Appendix L: Theoretical Framework for ERP implementation



L1: Theoretical framework for ERP implementation (Kettinger & Grover, 1995)

Appendix M: Taxonomy for critical ERP factors



M1: Critical ERP factors (Al-Mashari et al., 2003)

Appendix N: Operator Skill set

Legend

QR OP x	*Qualification Operator x*
TE OP x	*Test Engineering Operator x*
Man. El. Test	*Manual Electrical Test*
Sens. Test	*Sensitivity Test*
Packaging	*Packaging*
L./U. machinery	*Loading / unloading machinery*
L./U. BI Boards	*Loading / unloading Burn In Boards*
Vis. Inc. Insp.	*Visual Incoming Inspection*
FL / GL Test	*Fine Leak / Gross Leak Test*
Control Q&R	*Controlling Q&R Test (HTOL, THB)*
Control TE	*Controlling TE Test (Failure ID, Jam prevention)*

N1: Legend

		Skills								
		Man. El. Test	*Sens. Test*	*Packaging*	*L./U. machinery*	*L./U. BI Boards*	*Vis. Inc. Insp.*	*FL / GL Test*	*Control Q&R*	*Control TE*
Operator										
	QR OP 1	x	x	x	x	x	x	x	x	x
	QR OP 2	x	x	x	x	x	x	x	x	x
	QR OP 3	x	x	x	x	x	x	x	x	
	QR OP 4	x	x	x	x	x	x	x	x	
	QR OP 5	x	x	x	x	x	x	x	x	
	TE OP 1	x		x	x	x	x			x
	TE OP 2	x		x	x	x	x			x
	TE OP 3	x	x	x	x	x	x			x
	TE OP 4	x		x	x	x	x			x
	TE OP 5	x	x	x	x	x	x			x
	TE OP 6	x		x	x	x	x			x
	TE OP 7	x		x	x	x	x			x
	TE OP 8	x		x	x	x	x			x
	TE OP 9	x		x	x	x	x			x
	TE OP 10	x		x	x	x	x			x

N2: Operator Skill set