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Summary

Title: “It’s easier to swallow an elephant in pieces…” A way of measuring Flexibility and Quality – *A study of Dynamic Assembly System*

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Problem discussion: Upon marketing the system in Europe and the USA cost savings generated from reduced work force have been prevailing. Since the cost of labour is much lower in the Asia Pacific region other factors have to be stressed. The parameters of flexibility and quality assurance may however cover any initial investment in a production system.

Purpose: Our purpose is to value flexibility and quality in a manufacturing context, applied to DAS, in order to use it in investment calculations.

Methodology: Case studies have been conducted at two manufacturing companies in Singapore. The benefits with case studies were the ability to deal with a full variety of figures and the possibility to study more complex problems. A part of our thesis was to develop a theoretical model. This was done through combining existing theories and the authors own experience and knowledge in the light of the case studies.

Conclusions: In order to make an adequate estimation of different companies, due to problems associated with acquiring correct figures, the Key Success Factors needs to be examined so that the gathering of numbers can be conducted with more focus. The model developed by the authors has some drawbacks and needs to be assessed further but provides an initial sufficient way of measuring flexibility and quality.

Keywords: Flexible manufacturing systems, Flexibility, Quality, Return on investment, Investment, Manufacturing, Dynamic Assembly System

Preface

First we would like to thank Mattias Perjos at FlexLink for initiating the thesis and thereby allowing us to go to Singapore for four months and have a blast.

We would also like to thank Jörgen Hedström, Claes Olander and Janne Leppaaho at FlexLink for taking the time and answering all our questions.

Further we would like to thank our tutors Mats Andersson, Gunilla Nordström, and David Nyberg for giving us feedback on our work.

The authors would also like to express additional great gratitude towards Gunilla for assistance, feedback and support going way beyond the call of duty.

"It's easier to swallow an elephant in pieces…"
Mattis Perjos 12.02.2004

Lund 14-05-2004

Cecilia Gröning, Niklas Roupé & Henrik Silfverstolpe

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1 Introduction

The chapter aims at providing a background to the thesis by initiating the reader into the trends on the market and the framework from which the initial problems, and thereby the assignment, was derived. The purpose of the report is also stated as well as the delimitations set in order to achieve it. The target group of the paper is defined and finally a brief presentation of what its different parts will entail is presented.

1.1 Background

Due to recent changes in the market demands on manufacturers of consumer goods many industries are going through restructuring. The changes are, amongst other things, globalisation and rapid advances in process technology[1]. The criteria describing reasons for the make or fail of a product can be divided into those that make the product *qualify* to compete about orders and those that can be denoted *order winners*[2]. The authors of this paper argue that the former *order winner* of *quality* has been demoted to a *qualifier* and is thereby not an actual competitive advantage but a prerequisite for competing on the market at all, i.e. quality is a characteristic that has to be present for the company to survive on the market place. Since the changes, and interaction, between *qualifiers* and *order winners* are ever present companies need to be flexible to cope and sustain their competitive advantage[3]. Flexibility is also of an outmost importance and is increasingly becoming one of the focal points in business in order to be able to comply with the increasing market demands resulting in shorter product cycles. The demand for a greater number of products/models made available simultaneously has also increased the importance of production flexibility. The concept of flexibility has therefore lately gained as a major competitive priority and will most likely continue to increasingly be so on the market that is changing ever-increasingly[4, 5]. The importance of increasing flexibility and setting a sustainable quality standard for the company is not simply a question of cutting costs or increasing revenues but in some sense a prerequisite for competing on the market as a whole. It should however be stated that the focus of the market also constantly changes as stated by Slack (1987), *"Flexibility is fashionable"* [6]

Across the board companies use the much acknowledged yet somewhat outdated Return on Investment that henceforth will be denoted simply ROI. The classic definition of ROI does not include hard to define measurables like quality and flexibility and it is up to each and every one applying it to try to calculate and incorporate them into it. This is mainly due to the great difficulties associated with trying to transform such concepts as quality and flexibility into monetary terms. The fact that there is not one unanimous definition of these but rather a vast number of such also adds to the difficulties when calculating the costs/revenues. The authors

[1] Mahrabi, Ulsoy, Koren, Heytler (2002)
[2] Hill (2000)
[3] Nilsson, Nordahl (1995), p. 8
[4] Mahrabi, Ulsoy, Koren, Heytler (2002)
[5] Nilsson, Nordahl (1995), p. 5
[6] Slack (1987), p. 35

further argue that the usage of ROI has accordingly become obsolete in its original form and needs to be developed further.

1.1.1 FlexLink

The assignment originated from FlexLink which at present has 543 employees and generates annual revenues exceeding a milliard SEK. Headquarters are situated in Gothenburg, Sweden and the main office for the Asia-Pacific region is located in Singapore. The product scope includes a range of different manufacturing systems and the modules that comprise it.

FlexLink initially designed and implemented conveyer belts for SKF, Svenska Kullager Fabriken. The knowledge acquired was later used when developing the products included today in the product scope. One of these products, or rather concept, is DAS, short for Dynamic Assembly System. As the name implies it is a production system built to fit dynamic industries with high flexibility and quality standards. The base of the system is modular thinking both on the software and hardware dimensions. The physical attributes of the system comprise automated modules, work stations and conveyer belts connecting these. The key factors for the system, besides the advantage of reducing labour costs that accompanies many production systems, are quality assurance and flexibility, among other advantages such as ergonomics, and the ability to handle many different products, and variations of these, at the same time within the same production system. The level of automation however does not define the system. The system can be configured to do assembly in a completely manual way as well as a combination of manual and automated operations.

The concept has previously been marketed in the EU and the USA. Attempts have been made to market the system in the Asia-Pacific region without success. FlexLink consequently wants to investigate if it is possible to market and sell the DAS concept in the Asia-Pacific region. The main reason why FlexLink may encounter problems when selling the system in Asia-Pacific is because of the lower production costs. The system is in the top range of the market for similar production systems and some of its advantages can be met by increasing the number of staff. Hence they want to investigate in what way they could improve their possibilities of selling the system to production companies in the region. Since the price level in Singapore is between that in Europe and that in most of the rest of Asia the case study companies studied are situated there. If the costs savings made are not sufficient enough to support investments here they are not likely to prove sufficient in other parts of the region.

1.2 Problem discussion

When determining whether or not the system can be successfully marketed in the region several factors have to be taken into account. When the system has been sold in the EU and the USA focus has been on cost savings originating from a lot of different sources, among others savings from decreased labour costs, automatic documentation and traceability. In the US the acquiring FDA (US Food and Drug Administration) validation has also been an additional driving force to some medical device manufacturers.

In order to introduce DAS at production companies in Singapore it is necessary to introduce the monetary effects of increased flexibility, higher degree of process control, and quality assurance into the concept of ROI to clarify the presumed benefits of the concept.

The conditions and prerequisites of the assignment, and subsequently the paper, can be summed up in the following questions:

- Is there any need of flexibility, process control and a higher degree of quality assurance at the case companies? Can any savings be obtained due to theses factors?
- Do the savings of flexibility and quality calculated in monetary terms reach levels sufficient to cover the initial investment for the system? Is DAS suitable/not suitable for the case companies?

These sub-questions will enable us to answer the following question:

- How can the concepts of flexibility and quality be introduced into ROI in order to put emphasis on potential advantages of DAS?

1.3 Purpose

Our purpose is to value flexibility and quality in a manufacturing context, applied to DAS, in order to use it in investment calculations.

1.4 Delimitations

The thesis will focus on flexibility and quality within the manufacturing system and mainly concern the assembling since the system at hand first and foremost is an assembly system even though it affects other parts of the supply chain.

Factors concerning ergonomics, and other more intangible aspects such as supplier relations, that are associated with flexibility, that are staff oriented such as high worker involvement, flexible wage schemes and worker competence, will not be considered in the report due to the difficulties collecting data concerning this.

Quality will be evaluated within the assembly line only and therefore mainly focus on failure, repairs, and how these are tracked and documented.

ROI will be considered to be the main way of determining whether or not to invest used by companies.

Technical changes to DAS will not be addressed. The system will also not be compared to other similar assembly systems.

Since the report will mainly focus on the manufacturing of products, having DAS in mind, *corporate overhead* will not be evaluated since these should not be affected to any major extent by the introduction of the system. The overhead costs used are factory over head.

Furthermore the thesis is not concerned with whether or not other companies market and sell similar concepts in Singapore.

1.5 Target group

The target group of the thesis is comprised of employees at FlexLink and at the studied case companies as well as students and teachers at the Lund University of Technology and at School of Economics and Management at the University of Lund. The students and teachers mainly focused on are however associated with Technology Management at the University of Lund.

1.6 Disposition

Chapter 1 ”Introduction”
The chapter aims at providing a background to the thesis by initiating the reader into the trends on the market and the framework from which the initial problems, and thereby the assignment, was derived. The purpose of the report is also stated as well as the delimitations set in order to achieve it. The target group of the paper is defined and finally a brief presentation of what its different parts will entail is presented.

Chapter 2 “Methodology”
In this chapter theories concerning the collection of data and how this should be managed are presented as well as a full description of in what manner this was actually conducted. How the collecting was advanced and what choices were made given the theories is discussed and evaluated. Basic assumptions made and methodological reflections are presented. Questions raised, regarding reliability and validity, during the collection, and processing, of the data are also discussed.

Chapter 3 “DAS”
An empirical explanation of DAS and its components is made in order to make the following chapters more accessible and comprehensible.

Chapter 4 “Theory”
Established theories that will later be used in the analysis to evaluate, sustain or discard the empirical data are presented here. The main foundation of the literature used in the paper is displayed and serves as a stepping-stone from which the decision on what empirical data is needed have been made. Factors of interest, definitions and formulas concerning flexibility, quality, ROI, flexible assembly systems and their characteristics are thereby presented here.

Chapter 5 “Framework for the theory interpretation and development”
An explanatory framework of how the literature reviewed in the previous chapter is interpreted and developed in the following is given.

Chapter 6 “Theory interpretation and development”
The students own conclusions regarding the theories are revealed and additional, by them developed, theoretical framework is presented for further analysis. The model is thereby developed and the formulas and approaches can be put into use.

Chapter 7 “Empirical study”
The two case study companies and the gathered essential information from them, is presented. The information has been collected based on the interview guide found in Appendix 4.

Chapter 8 “Analysis”
The theoretical framework and the empirical material are connected and create the base for the analysis. The analysis is divided into three parts. In the first part, calculations on the case companies are made and the results are discussed. The second part discusses the prerequisites for DAS and where the system is suitable. This is made to get a better understanding of the results at the case companies and to discuss in what contexts DAS is suitable. In the last part of the analysis the theoretical interpretation and development of the model is discussed. The aim is to highlight the strengths and weaknesses of the model and to discuss the model’s usefulness.

Chapter 9 “Conclusions”
In this chapter final conclusions are made based on the previous chapters. This chapter aims at answering the questions asked in the problem discussion as well as fulfilling the purpose of the report.

Chapter 10 “Further Research”
Suggestions for further, complementing research is presented based mainly on the analysis and the conclusions and to some extent also on the preceding chapters.

2 Methodology

In this chapter theories concerning the collection of data and how this should be managed are presented as well as a full description of in what manner this was actually conducted. How this collecting was advanced and what choices were made given the theories is discussed and evaluated. Basic assumptions made and methodological reflections are presented. Questions raised, regarding reliability and validity, during the collection, and processing, of the data are also discussed.

2.1 Methodology reflections

We, the three authors of the thesis, come from different backgrounds; two of us come from business administration and one from mechanical engineering. Our different backgrounds have been useful when addressing the research problem. The thesis involves a broad spectrum of theories and different skills and knowledge have facilitated the research. Our different backgrounds have also been useful during the case studies. We have noticed different things, leading to broader information spectra. Since we have different backgrounds, we also at first had different assumptions. The research question and purpose have been heavily discussed, leading to a common consensus and a greater focus.

The purpose of the thesis is to value flexibility and quality in a manufacturing context, applied to DAS, in order to use the value in investment calculations. To be able to fulfil our purpose we have chosen a case study approach. To structure our work we have made a research design. In the following part we describe this research design, explaining how the data was collected and how we have structured and used it.

2.2 Research method

According to Yin (1994) there are several ways of doing social science research. Different strategies for this kind of research are case study, experiments, surveys, histories and the analysis of archival information. Each strategy can be used for three purposes, exploratory, descriptive, or explanatory. The different purposes do not differentiate the strategies, instead when to use each strategy depends upon three conditions: (a) the type of research question posed, (b) the extent of control an investigator has over actual behavioural events, and (c) the degree of focus on the contemporary as opposed to historical events. Depending on the conditions the strategies have different advantages and disadvantages. Some situations may have no clear preferred strategy, as the strengths and weaknesses of the various strategies may overlap.[7]

Yin states that the first condition to identify is the actual research question being asked since this is the most important factor for differentiating between various research strategies. The familiar series of “who”, “what”, “where”, “how”, and “why” are used to categorise the type of question. “What” questions are in general either

[7] Yin, R. (1994), p. 1-4

exploratory, when any of the strategies could be used, or prevalence, when surveys or the analysis of archival data are preferred. The research goal of ”who” and “where” questions, is to describe the incidence or prevalence of a phenomenon. This case is likely to lead to the use of surveys or analysis of archival data. “How” and “why” questions are more explanatory and favour the use of case studies, histories, or experiments.[8]

There are situations in which all research strategies can be relevant and other situations in which some strategies are preferable. To do a further distinction between the strategies the two remaining conditions (b and c) can be used. In the “how” and “why” cases histories are the preferred strategy when there is no control and the study is focused on historical events. For this strategy the investigator must rely on documents as the main source of evidence. Case studies are preferred when examining contemporary sets of events over which the investigator has little or no control. Histories can be done over contemporary events and overlap the strategy of the case study. One benefit with case studies is the ability to deal with a full variety of evidence. Beyond what is available in the conventional historical study, the case study uses documents, artefacts, interviews, and observations. Experiments are preferred when an investigator can manipulate behaviour directly or systematically. This can occur in a laboratory setting or in a field setting.[9]

To be able to fulfil the purpose of our study, we have chosen to do case studies. Many surveys made are done using questionnaires. To investigate how to value flexibility and quality, we needed to observe several aspects of the problem and we did not believe this could be done by using questionnaires. By doing case studies we were able to study a more complex problem, and since we had no control over the investigated events we believe that case studies were favourable for us. For our research we have done both exploratory and explanatory case studies.

Because of lack of applicable theories, a part of our thesis was to develop our own theoretical model. This was partly done trough combining existing theories and partly through the authors own experience and knowledge in the light of the case studies. According to Eisenhardt (1989) combining observations from previous literature, common sense, and experience has traditionally led to the development of new theories. Case studies play a major role, when developing these theories.[10]

2.3 Research design

Yin defines the research design as the logical sequence that connects the empirical data to a study’s initial research question and, ultimately, to its conclusions. In other words it is an action plan for getting from here to there, where here is the initial set of questions to be answered, and there are conclusions regarding these questions.[11]

Our research questions derive from an assignment initiated by FlexLink. The problem formulation and purpose was redefined to enclose both a practical and theoretical

[8] Yin, R. (1994), p. 5-7
[9] Yin, R. (1994), p. 8-10
[10] Eisenhardt K.M. (1989), pp. 533
[11] Yin, R. (1994) p. 19

aspect. The assignment was approached in a manner more focused on DAS as a concept rather than a specific solution, i.e. specific solutions at the case study companies such as adjusted technological modules and breakdown of operations were not made. This approach was derived from a more general understanding of the system.

To be able to answer the questions in a structured way, we have designed a research plan that divides our work into five different steps. There are no clear boundaries between the different steps; instead the process must be seen as iterative. We have used an abductive approach for our study. This approach involves an iterative movement between theory and empirical observations, with the starting point in the latter. A continuous iterative reinterpretation of theory and empirical observations is done throughout the research process. To develop an initial theoretical framework, a deep understanding of existing theory is required. This also helps the researchers to understand the empirical observations in the analytical phase.[12]

The abductive approach has been suitable for our thesis. Figure 1 show how the abductive approach has been used during the process. The subject was complex and the theories concerning it are ambiguous. In order to do our research we have to develop our own theoretical framework, on the basis of combining existing theory, empirical material, and experience. The abductive approach has allowed us to do iterative movements between theory and empirical research helping us to understand the problems and do further theoretical developments.

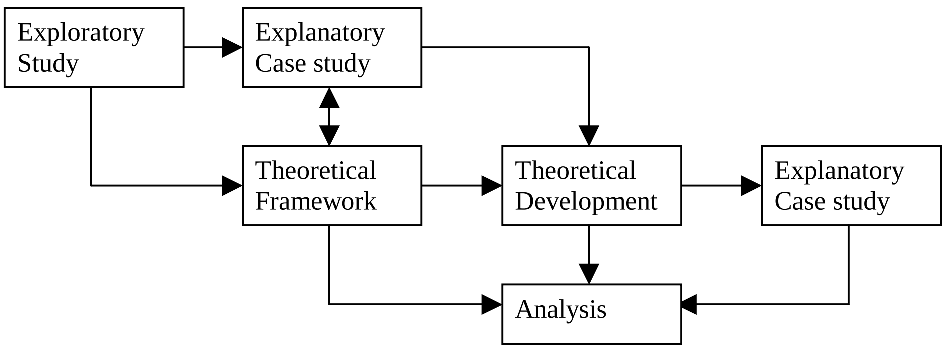

Figure 1 Schematic picture of the process

2.3.1 Step 1. Exploratory study in Sweden

To be able to fulfil our purpose and to address the problem, great understanding and knowledge about DAS was needed. Through FlexLink thorough information regarding the system was obtained. The first meeting was held with Klas Ålander, Marketing Manager, at FlexLink's headquarters in Gothenburg 29.12.2003 explaining the system theoretically and the considerations that led to its creation. More information about the system was later attained from Mattias Perjos, Managing Director, Asia Pacific FlexLink and Jörgen Hedström, Sales and Marketing Manager at FlexLink. To get an even deeper understanding and more objective information an exploratory study was accomplished at company X in Sweden, where DAS had been implemented. The empirical material is presented in a way that does not reveal the

[12] Eisenhardt K.M. (1989) pp. 533

company. Therefore the type of products, name of employees and historical background are left out. This is also applied to the case study companies in Singapore, presented below.

The objective of the study at company X was to explore DAS, in order to learn more about the system and the system's impact on flexibility and quality. The aim of the study was also to get a starting point for the research and a better understanding of what theories were required. A meeting with company X was arranged 19.01.2004 with the Manager Production Development at company X in order to get a first insight into DAS as a means of assembly system in practice. Company X manufactures "back-pack" sized electronic equipment using both manual and automated operations within the assembly. A tour of the plant was conducted followed by an interview and a presentation of the system adapted to the plant at hand and the benefits coupled with this. Information concerning the implementation of the system was made available and questions raised from the tour were discussed. The information attained through the explorative study has given us a deeper knowledge of DAS. The information was also the basis for further case studies and proved helpful when developing our own theoretical model.

2.3.2 Step 2. Theoretical framework

The choice of existing theory was based on both the research question and on the outcome of the exploratory study. To build a broad theoretical basis for our thesis and for the case studies, theories about manufacturing, flexible manufacturing systems, Return on Investment, Key Success Factors, cost drivers, flexibility, and quality was studied. Empirical and theoretical studies have to some extent been conducted as an iterative process, which enabled us to better understand the empirical material and to make reinterpretations of the theory.

This thesis focuses on flexibility and quality in a manufacturing context. Theories about manufacturing and cost relating to the manufacturing was therefore of interest. To evaluate an investment in DAS, it was not only important to have a great knowledge about DAS, but also to know the prerequisites and factors affecting manufacturing systems, especially flexible manufacturing systems. Theories concerning this kind of manufacturing systems represent a part of the theoretical basis.

Traditional techniques of financial analysis are often used in evaluating investments. ROI is the most commonly used management indicator of company profit and performance.[13] FlexLink uses ROI when formulating proposals to its customer and ROI is important to their customers when deciding upon what investments to make.[14] To make the outcome of this thesis useful for FlexLink the value of flexibility and quality has been included into ROI. Theories about this technique was therefore of value for our thesis.

[13] Friedlob, G.T, Franklin, J.P (1996)
[14] Mattias Perjos. Managing Director, Asia Pacific. FlexLink. 15.01.2004

To evaluate the need of flexibility and quality in different industries theories about KSF was used. The definitions of flexibility and quality were broken down and quantified using cost drivers.

To fulfil our purpose and value flexibility and quality in a manufacturing context, theories about flexibility and quality were needed. These theories have helped us understand important factors when addressing flexibility and quality in a manufacturing context. To value flexibility and quality we first needed to define the two factors. The theories about quality are rather uniform, while the theories about flexibility are very diverse. In the literature over 70 terms of flexibility can be found[15]. Besides the lack of clear definitions of flexibility, there are also a lack of theories about how to measure and value flexibility. Since this is a major part of our thesis, we have to develop our own theoretical model for the thesis, called *theoretical interpretation and development*. The theoretical framework has been the basis for the development of this model.

2.3.3 Step 3. Theoretical interpretation and development

The model was done partly through combining existing literature and theoretical formulas, and partly as a development of new assumptions based on the students experience and knowledge, and the outcome of the case studies. The theoretical development and interpretation was then the base for further research within the case companies, and later on together with the theoretical framework the basis for the analysis.

Theories describe models as an incomplete picture of reality[16]. Economic models are often used as a simplified description of reality, and are often in simple cases described as diagrams, and in more complicated cases as equation systems with mathematical solutions[17]. Other types of models are physical, mathematical, and analogous models. The physical models are more concrete, whilst the mathematical models are more abstract[18]. Our model evaluates the economic aspects of a potential implementation of DAS. This is done by the use of manufacturing formulas and mathematical equations.

The simplifications of reality are often seen as the basis when developing models, but are also the main source for criticism. Common criticism is that models are too disconnected from reality.[19] The criterion of simplicity was only partly considered in our model. When developing our model it was important to reproduce a potential implementation of DAS, and a simplification was from this point of view not possible. We also believe that when dealing with complex subjects as flexibility and quality it is important to consider many aspects and data to increase the accuracy. On the other hand we used cost drivers to break down the definitions of flexibility and quality in order to facilitate an understanding of the otherwise complex subjects.

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15 Shewchuk, J.P, Moodie, C. (1998), pp. 325
16 Edlund, Högberg, Leonardz (1999), pp. 29
17 Eklund (1999) pp. 17
18 Edlund, Högberg, Leonardz (1999), pp. 29
19 Eklund (1999) pp. 17

Nicholson stresses that testing the validity of an economic model is a very difficult task. Two methods can be used upon verifying models. The model's validity can be based on "reasonable" assumptions or on how well they can explain economic events in the real world.[20] Our model is adapted to DAS and provides quite a good display of the affects an implementation would have. The development of theories by the researchers probably has had an impact on the results and the assumptions made. An awareness of the problem at hand however limited this.

2.3.4 Step 4. Case studies in Singapore

To evaluate an investment of DAS, we needed to compare the system used by the case companies with the potential differences DAS would make at the case companies. The figures needed from the current systems have been collected through case studies at company Y and Z in Singapore. The information is focused on the data of the assembly systems presently used. All data was collected between the 1st of March and the 30th of April.

Since DAS is not installed at either of the case companies, or at other companies in the Asia-Pacific region, the figures needed regarding DAS could not be obtained through case studies. To get comparable figures for DAS, we have participated in simulations of DAS at the case companies, interviewed experts on DAS, used our own knowledge and experience about DAS and the case companies, and benchmarked figures from company X.

We have not been able to choose the case companies, instead company Y and Z have been chosen by FlexLink. To chose the companies the assigner sent out a request to several companies in the region. Even if several companies responded and showed interest, few were interested in sharing the kind of information that was required. The two case companies were chosen on the basis that they were willing to provide information and that they were able to spend time on interviews and the gathering of information needed. The companies were not chosen on the premise that they would be suitable for DAS. The purpose with the case studies was at first to get an understanding about the case companies and the manufacturing prerequisites the companies were facing. Later on the focus of the case studies was on the data required according to the theoretical interpretation and the development of the model.

According to Yin (1994) the information in case studies may come from six sources: documents, archival records, interviews, direct observation, participant-observation, and physical artefacts. The various sources are highly complementary, and it is preferable to use as many sources as possible.[21] In our case studies we have used documents, interviews and direct observation. Most of the respondents were chosen because of their work in the assembly line, but some interviews were held with persons from other departments. The persons interviewed were chosen by a coordinator at each company directing the questions to the right person, collecting answers and/or booking meetings with persons deemed suitable. The interviews were made through a mix of open and closed questions. When we needed figures, closed

[20] Nicholson (2002) pp. 4
[21] Yin, R. (1994), p. 80

questions were preferable. Both personal interviews and interviews over e-mail have been done.

At company Y we had an initial meeting with the company management to get an overview over the company and to discuss the problem. Several persons were then interviewed. The respondents were production manager, line manager, persons from finance and costing, R&D, product development, and test and development. At company Z we have interviewed two persons, the managing director and the senior manufacturing engineer. Since company Z is a fairly small company it has been possible to obtain all information from these two persons. Both the managing director and the senior manufacturing engineer were interviewed several times. The managing director gave us general information about the company, and answered strategic questions. The senior manufacturing engineer answered questions regarding the assembly, and when needed, collected information from other persons in the organisation.

The personal interviews generally lasted one hour and the questions were always emailed in advance. The fact that the three authors of the thesis all attended the interviews made it possible to ask a broad spectrum of follow-up questions during the interviews. After the interviews additional questions was asked by e-mail. The three students all took notes during the interviews, which afterwards were compared, discussed, and adjusted.

Even though the interviews have given a lot of information, the observations have been an important source for gathering information and a great complement to the interviews. Observations in the assembly line have made it possible to confirm or discard information from interviews but also to get new information important to our thesis.

2.3.5 Step 5. Analysis and Conclusion

The final step in our research design was to analyse the empirical material in order to make conclusions regarding our research questions and purpose. This was done through the technique of pattern-matching, which is a way of relating the data to propositions.[22] The case companies and the empirical results were analysed to find either coincide or contradiction with the theoretical basis and our own theoretical model. This match was done to evaluate if the empirical results could strengthen or expand the theoretical model. The analysis was divided into three steps.

First, on the basis of our model the empirical data was calculated and the results presented and discussed, in order to evaluate if DAS was suitable at the case companies. A scenario analysis was made to get a better understanding of the importance of the different factors included in the model.

The next step of the analysis was to discuss the prerequisites for DAS and where the system is suitable. This was made to get an even better understanding of the results at the case companies and to discuss in what context DAS is suitable.

[22] Yin, R. (1994), pp. 26

In the last part of the analysis the theoretical interpretation and development model was analysed. The aim was to highlight the strengths and weaknesses of the model and to discuss the model's usefulness.

On the basis of the analysis, we have made conclusions about our practical and theoretical contribution.

One question raised during discussions was if the outcome of our case studies could be used in other cases. Yin (1994) stresses that case studies, like experiments, are possible to generalise to theoretical propositions but not to populations or universes. The goal of a case study is often to expand or generalise theories, in other words analytic generalisation, which is closely linked to pattern matching. To further explained analytic generalisation, this means that previously developed theory is used as a template with which to compare the empirical results of the case study.[23] Our theoretical development and interpretation model was developed to measure the value of flexibility and quality in a manufacturing context, and that is the level at which the generalisation of the case study can occur. With this thesis we hope to contribute on how to valuate flexibility and quality. Even if the study is done at two case companies, our hope is that our theoretical model can be used in other cases to value flexibility and quality in a manufacturing context.

2.4 Evaluation of the process

In this section we want to discuss the quality of the chosen research design for the thesis and how the work has proceeded. The standardised approach when evaluating a research is to use validity and reliability.[24]

The validity describes the accuracy of information in a research. The validity is also about defining instruments that really measures what they were intended to do. Validity also deals with the situation of the results being interpreted differently by the researchers and by other parts involved. It is important that the researchers consider as many aspects as possible of the studied object.[25]

We believe that the validity of the collected information is high. The authors have had the possibility to triangulate the information through interviewing several respondents at different levels in the organisation. Since several investigators have done the research, the collected information has been discussed and the interpretations compared.

An implementation of DAS includes several changes within the organisation. Resistance towards such changes can lead to unwillingness to provide accurate information or to describe the actual information in a subjective manner, which affects the validity. The use of different sources of information made it possible to verify the information and contributed to a higher validity. The difficulty to collect all information required can however have affected the validity of the results. All

[23] Yin, R. (1994), pp. 10
[24] Yin, R. (1994), p. 33
[25] Arbnor, I. & Bjerke, B. (1994), pp. 249

required data has not been possible to collect and in some cases it has been necessary to do assumptions primarily affecting the first section of the analysis. Even if the model used to value flexibility and quality has been modified during the process, some shortages might still exist, which can affect the validity of the results.

The reliability proves that the operations of a study, for example data collection procedures, can be repeated with the same results. The goal of reliability is to minimise the errors and biases in a study.[26] According to Arbnor & Bjerke (1994) it is difficult to do any reliable research in a changing and developing environment. This leads to less focus on the reliability of the research, and instead how to use the results becomes more important.[27]

FlexLink has chosen the case study companies and this of course has an impact on the outcome of the thesis. The companies were however not chosen on the criteria that they should be suitable for DAS. We do think that even if we, the authors of the paper, were not involved in the selection process, we have still been free to design the process and also to interpret the results independently. External requirements and influences from the assigning company might in some cases have affected our choices and way of doing things. Even if this would be the case, we do not think that this external pressure has had any settled impact on the result. We have been aware of the fact that the assigning company is more interested in the practical contribution than the theoretical. With help from supervisors at the university we have tried to balance out this situation.

[26] Yin, R. (1994), pp. 33
[27] Arbnor, I. & Bjerke, B. (1994), pp. 249

3 DAS

An empirical explanation of DAS and its components is made in order to make the following chapters more accessible and comprehensible.

DAS, a production concept fully owned by FlexLink, is short for Dynamic Assembly System, and is an intelligent pallet system dealing with both the physical material flow and the flow of information in the production process. Products are placed on pallets holding information about the specific individual product. The pallets are transferred between different work stations, usually consisting of manual work benches or automated machines, by conveyors and the flow is controlled by software also keeping track of statistics, visited work stations and so forth. The pallets used come in different standard sizes ranging from 240 mm x 240 mm to 560 mm x 560 mm. The software managing the system can display necessary information about the product at hand on a screen above each work station, e.g. tasks that needs to be performed, the order of these and other specific requirements. Because of the pallet system equipped with the escort memory each and every product connected to a specific order can be tracked.[28] This gives a high degree of control of the flow within the line decreasing problems with products being assembled incorrectly[29]. DAS leads to decreased manual handling of products and documentation. DAS software informs the operators what to do, what components to kit and where to place the components. The software also track orders, control the individual product, supply process information, test reports and follow-up support. This leads to a decreased number of failures.[30] Figure 2 gives a graphic overview of the composition of a standard DAS production line.

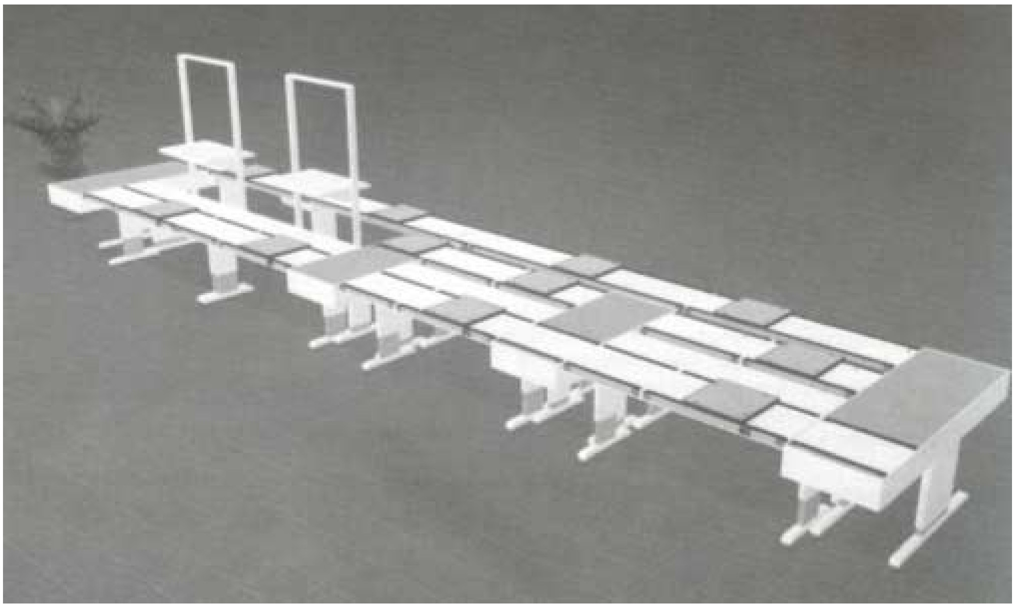

Figure 2 Graphic overview of a standard DAS production line

[28] Dynamic assembly systems. FlexLink. 2003
[29] Mattias Perjos. Managing Director, Asia Pacific. FlexLink. 07.01.2004 – 30.04.2004
[30] Jörgen Hedström. Sales and Marketing Manager. FlexLink. 22.04.2004

DAS can handle and integrate light assembly, inspection, testing, repairing and packaging applications. Thereby the system handles flow-oriented production. Within the flow, modular automation can be combined with manual assembly solutions. The system allows diverse products to be produced simultaneously. Production previously conducted in different lines can because of this run within the same line, thereby increasing overall capacity usage. This also facilitates the introduction of new products.[31] Normally there are multiple products at the same time in a DAS line. When introducing new products it is possible to change between new and old products. The reusability of DAS is between 70 to 80 percent. The changes required are changes of pallet and fixtures and of software recipes. The merger of lines also results in cleared floor space. Figures from implemented DAS tell that the cleared floor space is about 30 to 50 percent, depending on what system the customer had before the implementation. [32]

The system is made up of software and hardware modules. The different hardware modules use standardised interfaces with the plug-and-play concept to facilitate a fast integration of manual workstations and robot cells in the line. Therefore expanding an implemented system can be done at a low cost without major effects on the ongoing production. The reason for this is that no rebuilding is required but instead modules are added. DAS uses a software standard interface allowing robots and process-related equipment to connect to the system. For example the software used to control the production flow can be integrated with the customer's order systems enabling production to be directly governed by incoming orders.[33]

The main principles of the DAS concept are:[34]

- modularity
- standard interfaces
- material flow orientated dynamic production control
- dynamic buffers

DAS supports serial as well as parallel material flows. The main flow is governed by the main line always running, allowing pallets to enter parallel lines comprised of the different workstations when these are available.[35] This continuous flow secures a balancing of the workload in the different workstations. The continuous flow on the main line together with other parts of the system works as a dynamic buffer. DAS automatically directs the products in the buffer to the correct workstations. The order in which the products are assembled is set within the software, which then controls the material flow through the assembly line.[36] With DAS it is possible to integrate test and repair in the line. Should problems occur with products being assembled incorrectly the system automatically directs these products to repair stations and if necessary convert normal workstations into additional repair or test stations. Any

[31] Jörgen Hedström. Sales and Marketing Manager. FlexLink. 27.01.2004
[32] Jörgen Hedström. Sales and Marketing Manager. FlexLink. 22.04.2004
[33] Mattias Perjos. Managing Director, Asia Pacific. FlexLink. 07.01.2004 – 30.04.2004
[34] Dynamic assembly systems. FlexLink. 2003
[35] Klas Ålander. Marketing Manager. FlexLink. 27.12.2003
[36] Dynamic assembly systems. FlexLink. 2003

tracking of where failure occurred is then done automatically by the system accessing the process documentation stored in the database.[37] DAS has normally a repair route and immediately when a failure is detected the products are rerouted. If customers run batch production and do tests off line they detect failures at a late stage in the process, with high repair costs as a result. Real cases have shown a decreased cost of repairs by between 30 to 60 percent.[38]

The hardware modularity allows re-usability of equipment, reconfiguration of layouts and shortened delivery times[39]. The system lets production run smoother and more efficiently and therefore fewer operators can produce more which was the case at the company X[40]. The modularity also facilitates the rebuilding of a DAS line. It takes between 5 to 30 minutes to rebuild one module of DAS, depending on the layout configuration and where the module is located. The rebuilding of modules can be done while the line is running and the output will not be affected. When building an entire new DAS line around 2 to 5 days are required, depending on the complexity of the line. A line with manual workstations can be built and automated stations can be implemented gradually. When building a new line it is designed to reach utilisation as high as possible. The utilisation rate depends on the configuration and the mix of manual and automated processes. Manual lines can be run up to 99.7 percent and mixed lines between 96 to 98 percent.[41]

DAS in figures[42]

- Conveyor speed - 15 m/min
- Maximum pallet load -30 kg including pallet
- Maximum pallet width -480 mm for standard pallets

3.1 Hardware modules

The hardware of DAS is made up of a large variety of different modules. The most important basic modules are presented below:[43]

[37] Mattias Perjos. Managing Director, Asia Pacific. FlexLink. 07.01.2004 – 30.04.2004
[38] Jörgen Hedström. Sales and Marketing Manager. FlexLink. 22.04.2004
[39] Dynamic assembly systems. FlexLink. 2003
[40] Production manager. Company X. 19.01.2004
[41] Jörgen Hedström. Sales and Marketing Manager. FlexLink. 22.04.2004
[42] Dynamic assembly systems. FlexLink. 2003
[43] Dynamic assembly systems. FlexLink. 2003

3.1.1 Pallet DE-PA

Effective base for transportation and assembly

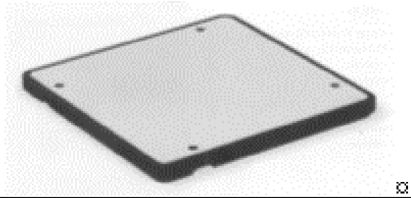	Standard features Available in several standard sizes Equipped with positioning holes Equipped with escort memory

Figure 3 Pallet DE-PA

3.1.2 Workstation DL-WS

Working place for manual assembly and inspection

This module moves the pallets to in front of the operator and back to the conveyor via a transverse conveyor. The module is equipped with a send button used to check out pallets after the dedicated operations are finished. The workstation can be equipped with FlexLink Quality Assurance Software QAS to give the operator instructions and to collect product and production related data.

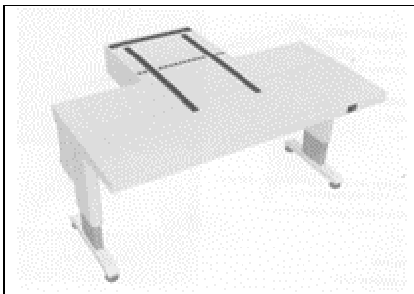	Standard features Segmented conveyor Pallet buffering capacity of one pallet Escort memory R/W system

Figure 4 Workstation DL-WS

3.1.3 Shuttle DL-SH

Module for transporting pallets and controlling material flow in the system

This module transports pallets from one conveyor or module to another enabling parallel material flow.

	Standard features One conveyor on a transverse linear drive unit Escort memory R/W system

Figure 5 Shuttle DL-SH

3.1.4 Main Line DL-ML

Module for transporting pallets

The main line module is made up of two sequential one-level conveyors transporting the pallets between the workstations. The module is commonly used between two shuttle modules.

	Standard features Segmented conveyors Escort memory R/W system Pallet buffering capacity of two pallets

Figure 6 Main Line DL-ML

3.1.5 Return Line DL-RL

Module for transporting pallets

The return line module provides a solution for closing the material loop. It has a single-level conveyor, which can be mounted beside, above or below other modules.

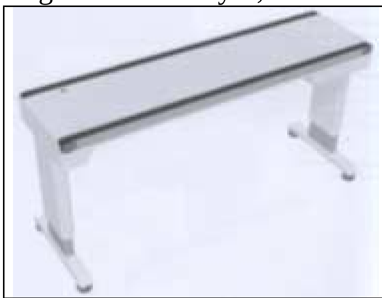	Standard features Segmented conveyor

Figure 7 Return Line DL-RL

3.2 Software modules

The software modularity offers different systems that automatically manage and control the material flow as well as the flow of information. The main different modules are Assembly Flow Management (AFM), Stock Flow Management (SFM), Quality Assurance System (QAS) and Machine Integration Management (MIM). The locations of the different modules within the system are shown in figure 8. The modules are presented below:[44]

[44] Dynamic assembly systems. FlexLink. 2003

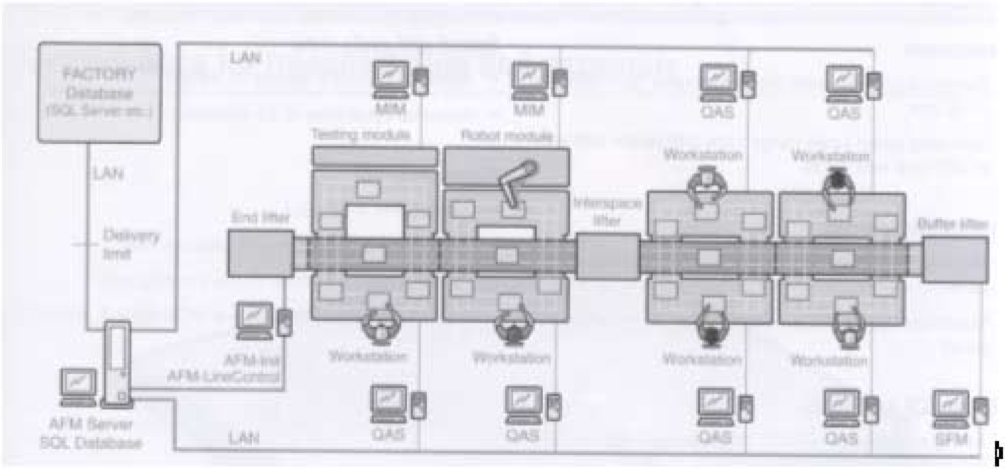

Figure 8 Locations of the modules in the system

3.2.1 AFM

This module controls the material flow and is possible to connect to factory MRP or ERP[45] allowing customer order initiated assembly. These orders can be manufactured in any order with the possibility to produce different orders and products simultaneously in the line. The software also includes a virtual reality link for simulation of production batches and changes in flow or capacity. This facilitates the ramp-up and cases have shown a utilisation of 94 to 96 percent one week after ramp-up start[46]. AFM also balances the mix and volume of different products, handles routes and collects process and product-related data, hence all documentation of the process is automated.

3.2.2 SFM

This module handles the tracking and replenishment of the stocks in DAS and controls material flow in buffer lifters and automatic stocks.

3.2.3 QAS

This is an interactive work instructor showing instructions to the operator on an attached screen either as text, pictures or videos. By providing the operator with instructions during the assembly process QAS decreases failures and improves quality. After introducing DAS at company X they no longer experienced any failures[47].

3.2.4 MIM

This software is a standardised modular interface between different control technologies in an automation cell. This enables easy integration of various robots and process-related equipment into DAS.

[45] MRP - Material Resource Planning, ERP - Enterprise Resource Planning
[46] Jörgen Hedström. Sales and Marketing Manager. FlexLink. 22.04.2004
[47] Production manager. Company X. 19.01.2004

4 Theory

Established theories that will later be used in the analysis to evaluate, sustain or discard, empirical data is presented here. The main foundation of the literature is used in the paper is displayed and serves as a stepping-stone from which the decision on what empirical data is needed have been made. Factors of interest, definitions and formulas concerning flexibility, quality, ROI, flexible assembly systems and their characteristics are thereby presented here.

4.1 Introduction

To facilitate the reading of this chapter, a short explanation on how the different theories were used in our study is made. Theories about flexibility and quality have helped us understand important factors when addressing flexibility and quality in a manufacturing context. To value flexibility and quality we first needed to define the two factors. Theories about manufacturing, and flexible manufacturing systems were used to get an understanding about the context, and to evaluate DAS in the light of the prerequisites and factors of a flexible manufacturing system. Theories concerning costs in manufacturing are used to trace important costs, and cost drivers are used to break down the definitions of flexibility and quality to facilitate the understanding. The cost drivers were then valued using manufacturing formulas. To make the outcome of this thesis useful for FlexLink the value of flexibility and quality has been included into ROI. To evaluate the need for flexibility and quality in different industries theories about KSF was used.

4.2 Definition of Flexibility

Flexibility originates from the Latin word for bendable[48] which in itself implies many of the specific characteristics of flexibility. The definitions of flexibility and what it is comprised of have been extensively discussed and investigated during the last three decades. Despite this, there is no general agreement on how it should be defined.[49] The scope of theories addressing flexibility ranges from factors as diverse as modifiability and organisation.

The literature describing all these factors is extensive but not in any way uniform. Since the report aims at determining the monetary terms related to flexibility and quality the definitions used will mainly consider measurables traceable to the assembly line rather than the whole of the value chain. It should however be mentioned that even harder to measure factors plays an important part in flexibility in terms of supplier relations, flexible wage schemes and high worker involvement[50]. Another hard to measure factor influencing flexibility that is disregarded in this paper is the workers competence[51].

[48] Grubbström & Olhager (1997), p. 74
[49] Shewchuk, Moodie (1998), p. 325
[50] Suarez et al. (1995)
[51] Nordahl,Nilsson, (1996), p.27

The important factor when defining flexibility is not to find a categorisation applicable to all situations or companies but to find one suitable for the one at hand and that can be shared by all involved. "*The objective of a classification system should not be to find an optimal system valid for all companies, but rather to find a satisfying classification to which managers in the company can relate.*"[52]

Because of the difficulties associated with finding one single definition of flexibility applicable an attempt to compile some of the main writer's opinions on the subject is presented here.

Output flexibility is defined by Nilsson & Nordahl (1995) as the flexibility that corresponds with what is identified on the market as being the *qualifiers* and *order winners*, i.e. it decides what flexibility factors that need to be present in order to accommodate the external demand[53]. This has been denoted differently by other authors, for example system level by Slack (1988)[54]. The theories reviewed nevertheless fall under this category no matter denotation.

Skinner (1985) divided flexibility into *process, product and volume*. Slack (1988) however stated that flexibility could be divided into the two sublevels of the system and the resource levels when evaluating company performance. The manufacturing tasks concerning the system level was categorised as *product, mix, volume* and *delivery flexibility*, which also influenced Nilsson & Nordahl (1995) later on.[55]

While attempting to define actual measurements of manufacturing flexibility Cox (1989) used simply *volume* and *product-mix* flexibility. Incorporated in the *mix flexibility* are to some extent also the costs associated with the introduction of *new products*.[56] In other cases incorporated in the parameter of *product*, *new products* is often included as in the case of Buffa (1984) where the two dimensions analysed were denoted *product variety* and *set-up time*[57] whilst also stating that a "*..competitor who can add a degree of flexibility to its positioning has a new marketing tool"*[58]. In the same year Hayes & Wheelwright also acknowledged flexibility as an important factor for competitive advantage dividing it into *product flexibility* and *volume flexibility*.[59]

Nilsson & Nordahl (1995) redefined Slack's definitions concerning internal and external flexibility. The external flexibility includes output flexibilities, "*which are found in the relationships between the company and its customers*", and input flexibilities "*found in the relationship between the company and its suppliers*"[60]. The internal flexibility was divided into the two characteristics of system level and resource level, not to be confused with Slack's levels. Output flexibility was

[52] Nilsson, Nordahl (1995), p.6
[53] Nilsson, Nordahl (1995), p 7
[54] Slack (1988)
[55] Slack (1988)
[56] Cox (1989), p. 68
[57] Buffa (1984), p. 158-159
[58] Buffa (1984), p. 163
[59] Hayes & Wheelwright (1984), p. 41
[60] Nilsson, Nordahl (1995), p. 7

translated into *product flexibility*, *mix flexibility*, *volume flexibility* and *delivery flexibility* which, as stated, are the equivalent of Slack's system level flexibility.

Chambers (1992) divided the concept of flexibility somewhat differently when he defined eight different categories, while simultaneously linking these to manufacturing strategy, namely: *technical range flexibility, volume flexibility, volume mix flexibility, seasonality flexibility, delivery speed flexibility, set-up timing flexibility, set-up reduction flexibility and quality flexibility*[61].

Olhager & West (2002) used only the three parameters of *volume, mix, and new product flexibility*. These are derived from studies of previous author's definition of what is defined as output flexibility[62].

Finally Suarez et al. (1995) used a framework based on a review of the literature on manufacturing strategy, and even though only using three of these in the study, stated that "*..we suggest there are four basic types of flexibility to consider: mix, new product, volume, and delivery time flexibility. We consider all other types of flexibility as variants of these four basic types.*"[63]

Even though many writers have defined the term of flexibility in many different ways, and by using many different approaches, some denotations and definitions are reoccurring which becomes evident upon reviewing Table 1 in which the denotation flexibility refers to output flexibility or system level flexibility as defined by Nilsson & Nordahl (1995), respectively Slack (1988).

Table 1 Types of flexibility identified/defined by different writers

Authors	*Skinner (1985)*	*Slack (1988)*	*Cox (1989)*	*Buffa (1984)*	*Hayes & Wheelwright (1984)*
Flexibility	Product	Product			Product
		Mix	Product-mix	Product variety	
	Volume	Volume	Volume	Volume	Volume
		Delivery flexibility			
	Process				

[61] Chambers, (1992), p. 292-293
[62] Olhager & West (2002), p. 66
[63] Suarez et al. (1995)

Authors	*Nilsson & Nordahl (1995)*	*Chambers (1992)*	*Olhager & West (2002)*	*Suarez et al. (1995)*
Flexibility	Product			
	Mix	Volume mix	Mix	Mix
	Volume	Volume	Volume	Volume
			New product flexibility	New product
	Delivery flexibility	Delivery speed		Delivery time flexibility
		Seasonality, Set-up timing, Set-up reduction Quality, Technical range		

The definitions of the single parameters vary but are to some extent collectively used by the main writers on the subject, presented above. We will not give a full reckoning of all the authors' different definitions but simply state that included in *product* is often the concept of *new product* and *mix* and that many of the others at times also are different expressions for the same definitions.

The flexibility definition in this thesis will be based on what Suarez et al. (1995) refers to as the "*four basic types of flexibility*"[64]; mix, new product, volume and delivery time flexibility.

4.3 Tradeoffs

4.3.1 Flexibility - Cost

There has traditionally been considered to be a trade-off between cost and flexibility[65] and according to Buffa (1984) "*A production system designed to emphasize cost and availability has given up its flexibility to a great extent*"[66]. This however has been challenged by amongst others Grubbström & Olhager (1997)[67] and Suarez et al. (1995)[68]. The contradictions surrounding this topic were consequently summed up by Olhager & West (2002) when they stated that "*in the end it all boils down to*

[64] Suarez et al. (1995)
[65] Olhager & West (2002), p. 64
[66] Buffa (1984), p. 34
[67] Grubbström & Olhager (1997), p. 75
[68] Suarez et al. (1995)

assessing whether the operational cost savings from a more flexible manufacturing system justify the additional investment[69]*"*.

4.3.2 Flexibility - Quality

Many times the characteristics of the factors of flexibility and quality may evoke the notion that there is a trade-off between them but this is not necessarily the case. Studies have shown that there is no direct correlation between the two.[70] Chambers (1992)[71] also has some input on the matter but due to the contradictions in opinions in the matter it is best summed up by simply stating that "*there is no common understanding as to how flexibility and quality are interrelated. Thus there may be a relationship, primarily related to the quality of input factors, but a situational context is needed to establish a comprehensible interpretation.*[72]*"*

4.3.3 Flexibility - Flexibility

The different types of flexibility seem to relate to one another rather than exclusively work against each other[73]. Mix flexibility is for example closely related to volume flexibility even thought studies have shown that there is no direct correlation between the two since the factors associated with them are so different. Mix flexibility often focuses on lean manufacturing and set-up times whilst volume flexibility mainly includes human resource policies[74]. This only states that a high degree of mix flexibility does not result in a higher or lower degree of volume flexibility or vice versa. That does not however mean that the two necessarily are not related. It can be argued that a company while maintaining mix flexibility often also have a broad product range, thereby experiencing less volume fluctuations, and hence may not need as much volume flexibility. The story of not keeping all your eggs in one basket, a philosophy put into practice by stockbrokers to hedge against risk, here comes into effect. [75]

When it comes to mix flexibility and new product flexibility these tend to reinforce each other. Slimming a factory down to only being able to produce one or a few products, thereby compromising their mix flexibility, results in diminishing new product flexibility. This also has the consequence of opening up to greater volume fluctuations. Conversely, companies that focus on new product flexibility and rapid new product introduction will thereby also in the long run be championing the mix flexibility which will have the effect of reducing volume fluctuations. [76]

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[69] Olhager & West (2002), p. 65
[70] Suarez et al. (1995)
[71] Chambers (1992)
[72] Olhager & West (2002), p. 63-64
[73] Nilsson, Nordahl, (1995), p. 9
[74] Nordahl, Nilsson, (1996) p. 26
[75] Suarez et al. (1995)
[76] Suarez et al. (1995)

4.4 Quality

4.4.1 Concepts of quality

Hoyer & Hoyer (2001) tries to explain the different quality gurus' definitions of quality that span a broad spectrum. "Even though there may be a great deal of agreement among the gurus, they do not agree on a consensus definition."[77]

The definitions of quality may also vary depending on what applications are reviewed. When concerned with manufacturing applications the term is "often defined as conformance to specifications or as meeting standards on the performance of the product."[78] The conformance dimension is the degree to which a product's design and operating characteristics meet established standards.[79]

4.4.2 Dealing with quality

There are two different approaches when dealing with quality issues. One is the reactive approach and the other one is the proactive approach. The reactive approach focuses on preventing "faulty work from being passed to subsequent processes". The proactive approach aims at preventing instead of detecting faulty work. This forces the company to do right the first time.[80] This idea should be interpreted carefully since in order to improve it is necessary to accept change and then also some mistakes during this process as long as the reasons for these mistakes are reviewed.[81]

One issue concerning conformance is when to do the checking of quality in the line. The most appropriate time is after an operation has been finished. This is normally not the case within the traditional production systems where the check of conformance is done after the production. How the company deals with this issue directly affects its "ability to minimise the repercussions of below-quality work".[82] The earlier in the process problems with quality are identified the greater are the possible cost savings. Costs rise by an order of magnitude per every step further along the production chain peaking if the problems arise in the field.[83]

Total quality cost can be lowered by increased efforts to improve quality as long as the cost per unit to fix quality failures is higher than the cost of preventing these failures.[84] This leads to a nonzero optimal defect level normally illustrated in the traditional model of quality costs. This optimal level occurs when the margin cost of conformance work reaches the same level as the margin cost of non-conformance work as illustrated in Figure 9.[85]

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[77] Hoyer, Hoyer et al. (2001), p. 54
[78] Karmarkar, Pitbladdo (1997), p. 27
[79] Garvin (1987), p. 108
[80] Hill, p. 250
[81] Bergman, Klefsjö, p. 31
[82] Hill, p. 250
[83] Garvin, pp. 79
[84] Garvin, p. 79
[85] Ittner (1996), p. 115

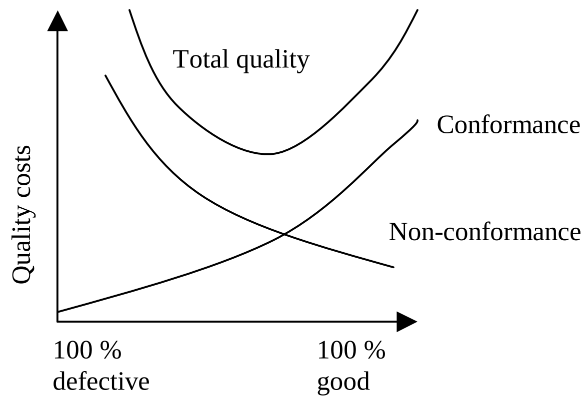


Figure 9 The traditional quality cost model

4.4.3 Quality costing

Groover defines time spent on checking quality and whether products fulfil the specifications as non-operation and non-value-adding time in Eq. [1] dealing with MLT. Thus all time used to confirm that a product has been manufactured according to specifications should be summed as T_{no} and used to evaluate the effect on the MLT as well as the cost structure of the production. Because of this all time spend on conformance work is to be considered a cost to the production.[86]

"Typically companies confine quality costs to four broad categories: prevention costs and appraisal costs seen as conformance costs and internal failure costs and external failure costs regarded as non-conformance costs"[87]. Kaoru Ishikawa did the introduction to these techniques in 1976[88]. Prevention costs include costs of activities undertaken to prevent non-conformance to occur. Appraisal costs are comprised of the costs spent on activities designed to search for mistakes once they have occurred. Internal failures incur costs from handling non-conforming products identified before the products reach the customer. External costs are costs incurred from non-conforming products reaching customers.[89] Table 2 summarises the four categories and add a few illustrating examples.

Table 2 Quality costs[90]

Conformance costs	Examples[91]
Prevention	Implementing and maintaining a quality system, quality-related training, new product reviews and quality planning.

[86] Groover, p. 30
[87] Garvin, p. 79
[88] Garvin, p. 301
[89] Garvin, p. 79
[90] Garvin, p. 79
[91] Ittner (1996), p. 115

Appraisal	Receiving, in-process and final inspection, lab tests and field tests.
Non-conformance costs	
Internal failure	Scrap, rework, spoilage, rescheduling, expediting and down-time.
External failure	Warranty charges, liability claims, penalties and opportunity costs of lost customer goodwill.

Quality costing is generally used by companies to identify excessive cost, waste and non-value adding activities thereby being able to counteract these activities and reduce total manufacturing costs. Many different approaches can be used when establishing a quality costing system. The reason for this being the difficulty when identifying quality costs since these, according to many writers, often are compounded by manufacturing process, system, products and company culture. One approach used is the traditional prevention-appraisal-failure (PAF) method based on the subdivision set by Ishikawa.[92] In some organisations this method and its terminology is used as the basis when assessing the quality costs.[93] For a long time the problems with identifying quality related activities have been discussed by authors on the subject. Even organisations applying the PAF model use different approaches.[94]

4.5 Manufacturing process

Depending on the type of production, the steps in a manufacturing process can differ. But to convert raw material into finished products the process of manufacturing must include five basic steps:[95]

- Processing
- Assembly
- Material handling and storage
- Inspection and testing
- Control

The first two of these operations that are value increasing for the product and are performed within the plant directly on the product. The following two are not directly value adding but must never the same be performed in the plant and effects the product physically. It should be mentioned that even though these are not considered to be value increasing to the product they still incur major costs to companies and thereby there are large savings to be made within these steps as well. The last step

[92] Dale, Wan (2002), p. 104
[93] Keogh, Dalrymple, Atkins (2003), p. 340
[94] Keogh, Dalrymple, Atkins (2003), p. 345
[95] Groover (1987), p. 21-24

however is required to plan, manage, and coordinate the physical activities taking place even though it is not affecting the finished product physically.[96]

4.5.1 Processing

The processing operations transform the raw material from one state to the other without adding material or components. What is added is instead energy in one form or the other, i.e. heat, electricity, chemical energy. This is done to change the shape of the material, remove proper material or achieve the set physical qualities.[97]

4.5.2 Assembly

After the preceding processing operations have been done assembling is the next step. Assembly is defined as the joining of two or more components by the use of welding, brazing, and soldering as well as the use of screws, nuts, rivets and other features.[98]

4.5.3 Material handling and storage

This is comprised by all the handling and moving of material between and within the processing and the assembly operations. Since this is a significant part of the time spent on transforming raw materials into the final product it is of an outmost importance that this is managed in an efficient manner.[99]

4.5.4 Inspection and testing

These operations are part of the quality control. Inspection usually aims at making sure that the product meets set design standards and specifications, e.g. measuring a specific part to assess whether or not its deviations are within the limits stated on the engineering drawing. Testing on the other hand is usually more concerned with the performance of the final product. It makes sure that the product operates correctly and can perform all the acquired features specified.[100]

4.5.5 Control

Within this concept all control ranging from the control of processing and assembly operations to the more general plant activities is included. This entails the effective use of labour, moving of material, shipping products and making sure the costs of the plant are minimised and utilised.[101]

4.6 Flexible manufacturing system

In the last decades, many companies have begun to make changes to their manufacturing processes[102]. Top managers have realised that survival and growth require equipment investments consistent with the marketing strategies[103]. Flexible manufacturing was pioneered in the United States as an answer to the reduced lot

[96] Groover (1987), p. 21-24
[97] Groover (1987), p. 21-24
[98] Groover (1987), p. 21-24
[99] Groover (1987), p. 21-24
[100] Groover (1987), p. 21-24
[101] Groover (1987), p. 21-24
[102] Maskell, B. (1989)
[103] Kaplow, I. (1989)

sizes, but the Japanese became the leaders in the installation of such systems[104]. Today there is no consistent definition on a flexile manufacturing system (FMS). Instead the explanations of what a FMS is, are almost equal to the number of users.[105]

Noghabai defines FMS as computer based production systems, which are developed in order to perform several operations with the possibility to change product very quickly.[106]

Buffa (1985) does not define FMS, instead he describes the different parts of the system. In FMS, numerical control machines on the line are controlled by a computer, robots handles the parts, and automatic guided carts carry finished products to their next locations. Automatic tool changing systems are incorporated, and product changeover is incorporated in the computer program. Thus, a wide variety of parts can be produced on the same flexible equipment.[107]

Groover (1987) defines FMS as a group of processing stations (predominantly computer numerical control machine tools), interconnected by means of an automated materials handling and storage system.[108]

Different FMS has different components. In general FMS include some kind of processing stations, material handling and storage, and a computer control system.[109]

Some writers point out that the entire process of FMS has to be automated, while others do not see this as a requirement. Even if the definitions differ, the effect of FMS is consistent. A flexible manufacturing system enables a greater customer service in the shape of earlier start-up times, shorter throughput times, closer completion dates and a greater opportunity to cancel and replace[110]. It can also improve quality, reduce lead times, reduce costs and enhance production flexibility, radically improving the company's competitiveness[111].

4.6.1 Benefits of FMS

Groove (1987) stresses several benefits and advantages with FMS, when properly applied, over alternative methods of production. These are as follows:[112]

Higher machine utilisation
More efficient work handling, off-line setups, and better scheduling contributes to that FMS achieves a higher average utilisation than machines in a conventional batch production.

[104] Buffa, E.S (1985), p. 97
[105] Kompendium Tillverkningssystem (2000), pp. 23
[106] Kompendium Tillverkningssystem (2000), p. 23
[107] Buffa, E.S (1985), p. 97
[108] Groover, M.P (1987), p. 463
[109] Kompendium Tillverkningssystem (2000), p. 29
[110] Kaplow, I. (1989)
[111] Maskell, B. (1989)
[112] Groover, M.P (1987), pp. 482

Reduced work-in process
The number of parts being processed at any certain time is less with FMS than in batched production. The explanation is that with FMS different parts are processed together rather than separate still connected to a certain batch.

Lower manufacturing lead times
The time spent in process by the parts is closely related to reduced work in process. The outcome of shorter lead times will be faster customer deliveries.

Greater flexibility in production scheduling
FMS gives a great opportunity to do quick adjustments in the production, to cancel and replace, in order to respond to rush orders and special customer requests.

Higher labour productivity
The higher labour productivity with FMS can be traced to the system's higher production rate capacity and its lower reliance on direct labour.

To point out other possible benefits, an investment in FMS can lead to lower labour costs, lower material costs, reduced stock, and reduced manufacturing cost.[113]

4.6.2 Where to apply FMS

Buffa (1985) discusses the importance of tying process technology to the positioning decision. Because FMS is based on flexibility and the logical emphasis on reducing lot sizes, this does not apply to all situations. When it applies it is important that a firm understands this since the competitor who can add a degree of flexibility to its positioning has a new marketing tool.[114] According to Groover (1987) FMS is considered to fill a gap between high production transfer lines and low production numerical control machines.[115]

4.7 Costs in manufacturing

A common way of assessing costs in manufacturing is to simply divide the total costs into its variable and fixed costs. This approach results in problems regarding accounting, hence this way of estimating costs tends not to be used and it will not be used here either. The costs will instead be calculated using the three parameters of *direct labour cost, material cost and overhead cost*. The *direct labour cost* is comprised of all the wages paid to personnel associated with the operation of the machines and the processing and assembling of the products. The *material cost* part consists of all the costs for all the raw material used to produce the final product. *Overhead cost* can be further divided into *factory overhead* and *corporate overhead*. *Factory overhead* includes all the costs that are not directly related to material or direct labour cost, i.e. plant supervision, line foremen, maintenance crew and so forth. For a more extensive presentation of factors that are commonly included in this see Table 3.[116]

[113] Kompendium Tillverkningssystem (2000), pp. 23
[114] Buffa, E.S (1985), p. 163
[115] Groover, M.P (1987), p. 465
[116] Groover, (1987), p. 55

Table 3 Typical factory overhead expenses

Plant supervision	Applicable taxes
Line foremen	Insurance
Maintenance crew	Heat
Custodial services	Light
Security personnel	Power for machines
Tool crib attendant	Factory costs
Materials handling crew	Equipment cost
Shipping and receiving	Fringe benefits

The *corporate overhead* is comprised of all the costs generated by activities not directly connected to the manufacturing. These are presented in Table 4.

Table 4 Typical corporate overhead expenses

Corporate executives	Applicable taxes
Sales personnel	Cost of office space
Accounting department	Security personnel
Finance department	Heat
Legal counsel	Light
Research and	Air conditioning development
Design and engineering	Insurance
Other support personnel	Fringe benefits

A problem that is commonly encountered when trying to calculate overall costs of production is that the component made up of the cost for the use of equipment is neglected in the ordinary *overhead cost*. The production costs should therefore be divided into *direct labour cost* and *machine cost*. Machine cost can easily be calculated by expressing the annual cost of the machine expressed as an hourly rate and contributed to the number of hours the machine is operated. The overhead for the machine accounts for the power, floor space, maintenance, and repair expenses tied to the particular machine. The dividing of the applicable overhead rate in Table 3 into what is applicable to the labour and what is applicable to the machine is somewhat of a judgement call, shown by the similarities of the two tables above, and varies between different companies.[117]

4.8 Cost drivers

Cost behaviour depends on a number of structural factors that influence the cost, which Porter (1985) terms cost drivers. Porter (1985) defines cost drivers as the structural causes of the cost of an activity, which can be more or less under a firm's control. The cost of a given activity can be determined by a combination of several cost drivers. It is not unusual that cost drivers interact and together determine the cost behaviour of a particular activity. The relative impact of cost drivers differs widely among activities. Diagnosing the cost drivers of each value activity allows a firm to

[117] Groover (1987), p. 55

gain sophisticated understanding of the sources of its relative cost position and how it might be changed.[118]

As mentioned above cost drivers often interact upon determining the cost of an activity. These interactions can take two forms; drivers either reinforce or counteract. Drivers can be related to each other in affecting cost, in other words they reinforce each other. Cost drivers can also counteract each other, meaning that they offset each other's effects. Improving position vis-à-vis one driver may worsen a firm's position vis-à-vis another.[119]

Identifying cost drivers and quantifying their effects on cost is not easy, and a number of methods can be employed. The easiest method is applicable when the cost drivers of a value activity are intuitively clear from examining basic economics. Another method of identifying cost drivers is for a firm to examine its own internal experience. Past cost data may allow a firm to plot its historical learning curves in a value activity. Cost drivers can also be determined from interviews with experts. The final method for identifying cost drivers is to compare the firm's cost in a value activity to its competitors' or compare competitors' costs to each other.[120]

4.9 Formulas in manufacturing

To calculate and analyse different factors and relations in manufacturing systems, different concepts and mathematical formulas can be used.[121] To further clarify the formulas a crib on the different variables specifying units and denotations can be found in *Appendix 3*.

The easiest way to divide production is into the two categories of operations and nonoperations. Nonoperations include material handling, storage, inspections and other reasons for delay through the production line. The amount of time it takes for a batch of products to make it through the entire line is called manufacturing lead-time and will henceforth be referred to as *MLT*. Using the parameters of set up time T_{SU}, the quantity of the batch Q, the operation time T_O and the nonoperation time spent at the machine or workstation $T_{NO,}$ calculations can be made on *MLT*. With n number of operations the calculation is as follows.[122]

$$MLT = \sum_{i=1}^{n} (T_{SUi} + Q \cdot T_{Oi} + T_{NOi}) \qquad [1]$$

In order to measure the fluctuations in production volume due to varying incoming orders a plant's maximum capacity, denoted *PC*, can be calculated. The term is used to define the maximum output of the plant, not to be confused with the actual output. To be able to calculate this, the production rate of each operation needs to be calculated since they are closely related. The production rate is denoted R_P defined as

[118] Porter, M.E (1985), p. 70
[119] Porter, M.E (1985), p. 84
[120] Porter, M.E (1985), pp. 86-87
[121] Kompendium Tillverkningssystem (2000), p. 41
[122] Groover, (1987), p.30

units per hour. Included in this are the factors of failures and repairs. Since the number of failures is denotated, q, the input needs to be $Q/(1-q)$. Taking this into account the batch time for a given machine becomes[123]:

$$\frac{batchtime}{machine} = T_{SU} + \frac{Q \cdot T_O}{(1-q)} \qquad [2]$$

Reduced by dividing with Q the production rate is therefore[124]:

$$Rp = \left(\frac{Q}{T_{SU} + \frac{Q \cdot T_O}{(1-q)}} \right) \qquad [3]$$

Setting the number of work centers to W, hours per shift as H and shifts per week as S_W the formula for PC can be defined as[125]:

$$PC = W \cdot S_W \cdot H \cdot Rp =$$

$$= W \cdot S_W \cdot H \left(\frac{Q}{T_{SU} + \frac{Q \cdot T_O}{(1-q)}} \right) \qquad [4]$$

When calculating upon the plant capacity the fraction made up by the number of parts actually being produced and the capacity are often defined as well. This is called utilisation and is denoted *U*[126]:

$$U = \frac{output}{PC} \qquad [5]$$

An important factor when measuring the monetary effects of shorter set up times, and therefore the *MLT*, is the number of products that is in the production line at any given time since this can be reduced. This is called work in process, *WIP*, and can be seen as inventory that is being transformed. Using the parameters a rough estimate can be made[127].

$$WIP = \frac{PC \cdot U}{S_W \cdot H}(MLT) \qquad [6]$$

Another important factor in production is the total cost invested in the part calculated by summarising the material cost, processing, inspection and handling cost. If this total cost is denoted C_{PC}, material cost is C_M, average production time per unit of

[123] Groover, (1987), p.32
[124] Groover, (1987), p.32
[125] Groover, (1987), p.34
[126] Groover, (1987), p.36
[127] Groover, (1987), p.34

product for given machine is T_P, the cost for set up times and operation times is C_O and the nonoperation cost is called C_{NO} the formula is[128]:

$$C_{PC} = C_M + \sum_{i=1}^{n} (C_O \cdot T_{Pi} + C_{NOi}) \qquad [7]$$

4.10 Return on investment

The principal purpose of financial analysis is to form judgements about the future. When basing the analysis primarily on historical information it is assumed that the historical trends will continue in the future. It is however important to watch for developments that might make the future different from the past.[129] The typical capital investment decision involves the comparison of present outlays and future benefits. To do an economic evaluation of a project's desirability, a decision rule for accepting or rejecting investment projects is required.[130]

There are a variety of rules to evaluate capital investment projects[131]. The variants can be divided into major categories. The main techniques are: [132]

- The payback method
- The return of investment analysis
- The discounted cash flow techniques

The principles of compound interest can be traced back to the Old Babylonian period (circa 1800-1600 BC) and present value tables can be found in the mathematical and early accounting literature of medieval Europe. The use of time-discounted methods of project evaluation did not start until the nineteenth century. Several reports in 1950 showed that the use of time-discounted methods was insignificant and that the firms preferred the simple accounting rate of return on total assets as their measure of profitability. The use of time-discounting methods has increased over time and there is a shift to more sophisticated methods of project evaluation. In spite of this many firms still use non-discounted methods such as simple pay-back or accounting rate of return, when estimating the profitability of alternative investments.[133]

Return on investment (ROI) is the most common measure of profitability. ROI can be used for several purposes. Creditors and owners use ROI to consider the company's ability to earn adequate rate of return, to provide information about the effectiveness of management, and to project future earnings of investments. Managers on the other hand use ROI to measure the performance of individual company segments, to evaluate capital expenditure proposals, and to assist in setting management goals.[134]

[128] Groover, (1987), p.63
[129] Friedlob, G.T (1996), p. 215
[130] Levy H, Sarnat M (1990), pp. 30
[131] Levy H, Sarnat M (1990), pp. 164
[132] Lowe, P. (1979), p. 95
[133] Levy H, Sarnat M (1990), pp. 164
[134] Fridlob, G.T, Franklin, J.P (1996), pp. 6

Despite the lack of provision for the time element of money this form of analysis is widely used[135]. The popularity can be traced to the simplicity of ROI[136].

ROI is defined as:

$$ROI = \frac{profit}{investment} \qquad [8]$$

The horizon when using ROI is the expected machine life. Since it is not easy to make a precise forecast of machine life, many companies establish a standard life forecast practice based on equipment categories. The return on capital does often vary over the life of the plant, and the deprecation of the equipment must be considered.[137]

To summarise the advantages, ROI is easy to understand, directly comparable to the cost of capital, normalises dissimilar activities so that they can be compared, comprehensive since it reflects all aspects of a business and it shows the results of capital investment decisions[138]. It is also easy to compare ROI with the returns on financial investments. It can be readily related to the yield of quoted company shares or the interest rate on borrowed money.[139]

ROI is often criticised for making a complex management process appear unrealistically simple. The most common problem, when using ROI, is that managers reject investments that, otherwise acceptable, reduce the manager's ROI.[140]

4.10.1 The need for new metrics

Many articles emphasize the problem of using traditional metrics when evaluating investments in flexible automation. Traditional techniques of financial analysis are often helpful when evaluating investments in familiar technologies. But when applied to investments in flexible automation the traditional financial techniques are often inadequate.[141] Maskell (1989) put emphasis on the fact that traditional methods of assessing payback on capital projects can constrain the introduction of new advanced manufacturing systems.[142]

The problem is that things that matter the most are the most difficult to measure[143]. A fundamental requirement when doing investments is to at least reach the level set by traditional calculations[144]. Traditional management accounting techniques such as return-on-investment calculations require an individual project to be cost justified over a predetermined period[145]. The results are that the most powerful benefits of

[135] Lowe, P. (1979), p. 100
[136] Fridlob, G.T, Franklin, J.P (1996)
[137] Lowe, P. (1979), pp. 98
[138] Fridlob, G.T, Franklin, J.P (1996), pp. 38
[139] Lowe, P. (1979), p. 100
[140] Fridlob, G.T, Franklin, J.P (1996), pp. 38
[141] Downing, T. (1989)
[142] Maskell, B. (1989)
[143] Downing, T. (1989)
[144] Downing, T. (1989)
[145] Maskell, B. (1989)

flexible automation systems are not included in these metrics, for example the value of improved on-line deliveries, being more flexible to customer demands, and reduced production lead time.

The lack of non financial metrics is a problem in many industries. The main problem in the IT industry for example is how to measure the value of information technology. Many IT investments will increase the customer satisfaction, but this is not considered in the traditional metrics.[146] Kaplow (1989) points out that justifying investments to improve flexibility even in a faster production cycle environment is not easy.[147]

During the last decades top managers have realised that survival and growth require equipment investments consistent with the marketing strategies. The investments should therefore be centred on a need for flexibility and quick response.[148] That is the main reason why there is a need for new metrics that go beyond traditional industrial-age measures that focus on cost analysis and savings[149].

4.10.2 Evaluation includes several levels

The most important work when evaluating an investment is to establish the worth of the investment in financial terms, a computation of the capital expenditure and the expected benefits. It is however important to see the investment evaluation from different perspectives, since it includes several levels. The financial evaluation is an important level, but other levels to consider are the *strategic and policy level*, and the *implementation level*. The *strategic and policy level* assesses the relevance of the investment proposal in relation to company objectives and policies. The *implementation level* questions the assumptions on which the case for an investment rests.[150]

Hill and Chambers (1991) states that many companies underestimate the essential task of matching manufacturing capabilities to the need of their chosen markets. When it comes to flexibility, this often is seen as a panacea and what level or type of flexibility needed is not considered.[151] Taylor (1989) agrees and argues that the comparative importance of flexibility versus other objectives to the corporate strategy must be addressed early on when addressing manufacturing strategy. Because the types of flexibility entail different requirements and their priority differs in different environments, it is important to make decisions fit to the manufacturing strategy.[152]

4.11 KSF

The key success factors determine a firm's ability to survive and succeed within an industry. These factors can be used to analyse a firm's competitive advantage. To evaluate a firm's ability to survive and prosper, and to identify the key success factors

[146] Violino, B. (1997)
[147] Kaplow, I. (1989)
[148] Kaplow, I. (1989)
[149] Violino, B. (1997), p. 36
[150] Lowe, P. (1979), pp. 86
[151] Hill, T., Chambers, S. (1991), pp. 5
[152] Cox, T. (1989), p. 69

two criteria must be considered. The first is that the firm must supply what the customer wants to buy and the second is that the firm must survive competition. To do this evaluation, the following two questions can be asked:

- What do customers want?
- What does the firm need to do to survive competition?

To answer the first question the firm must identify its customer, their needs and why the customers select one supplier's offerings in preference to others. After identifying the basis of the customers' selection, it is important to analyse the underlying factors. To answer the second question the basis of competition in the industry must be examined. It is important to find out what drives the competition, how intense the competition is, and what the key dimensions are.[153]

[153] Grant, R.M (1998), pp. 75

5 Theoretical framework

An explanatory framework of how the literature reviewed in the previous chapter is interpreted and developed in the following is given.

Many writers have stressed the difficulties of measuring the two factors, for example Slack (1983) stated that measuring flexibility is very difficult. The explanations mentioned are that flexibility is a measure of potential rather than performance, flexibility is not a single concept, and flexibility has three dimensions; range, cost and time.[154] Even if the difficulties of measuring flexibility and quality are discussed, the theories give little help on how to address the problem. To be able to measure flexibility and quality one needs to find useful definitions, break down the definitions into measurable factors and find formulas to calculate the factors. In the chapter called theoretical interpretation and development the authors of the thesis develop their own theoretical model to measure flexibility and quality. This is done by using and combining the theories presented in the theory chapter, but also by the use of the empirical studies and the authors' experience and knowledge.

The theory chapter clearly states that several writers have discussed flexibility, and that the theories are very diverse and no uniform definition exists. The theories on flexibility will be used to identify, to the thesis, suitable definitions. When defining flexibility the four main categories of volume flexibility, mix flexibility, new product flexibility and delivery time flexibility used by Suarez et al (1995) are used. These categories are used by most of the main writers on the subject but the definitions of these parameters vary. The theories about quality are more uniform and the categories of conformance and non-conformance with the sub-categories prevention costs, appraisal costs, internal failure costs and external failure costs are often used when talking about quality in manufacturing. These categories are well suited for the thesis and can be used without any redefinition, but all the subcategories will not be considered. Only prevention and internal failure are of interest when evaluating DAS. Table 5 shows an overview of the definitions used.

Table 5 Overview of used definitions of flexibility and quality

Flexibility	Volume flexibility
	Mix flexibility
	New product flexibility
	Delivery flexibility
Quality	Prevention
	Internal failure

The complexity with flexibility and quality is that it is not only difficult to measure, but it is also difficult to value the results in monetary terms. From the definitions of flexibility and quality a break down of these into measurable cost drivers is done. Common theories about manufacturing costs and key formulas in manufacturing,

[154] Slack, N. (1983), pp. 4 -14

presented in the theory chapter, to calculate and value the cost drivers in monetary terms will be used.

6 Theory interpretation and development

The students own conclusions regarding the theories are revealed and additional, by them developed, theoretical framework is presented for further analysis. The model is thereby developed and the formulas and approaches can be put into use.

The definition of a flexible manufacturing system includes factors as earlier start-up times, shorter throughput times, closer completion dates, greater opportunity to cancel and replace[155], improving quality, reducing lead times, reducing costs and enhancing production flexibility[156]. We have divided the cost savings into the categories of flexibility savings and quality savings. Since general assumptions about the tradeoffs between flexibility and quality can not be made when it comes to the output factors this will not be discussed further.

Through the explorative case study and theory about flexible manufacturing systems we have identified advantages arisen from an investment in DAS compared to conventional production methods. The complexity of DAS, like other flexible manufacturing system, gives rise to cost savings both when the system firstly is implemented, and as an effect of future changes of the system.

A complication when tracing the savings is that they affect not only the cost side, but also the revenue side of the calculations. The affects on revenue are also multifaceted and can be divided into loss of revenue and increased revenue.

To decide the value of the cost savings of a DAS-investment, a comparison is done to what the cost would be using the system preceding the investment. This can be estimated either by benchmarking historical data or by attaining estimates on future trends from the process manager. The authors only consider cost savings that would be different with an introduction of DAS.

6.1 Flexibility related savings

A full reckoning of all the authors' different definitions of the categories is not given, but in the light of some of the main authors we will define, for this thesis, useful definitions. On the basis of our definitions we will then do a further breakdown into measurable factors. Table 6 presents an overview, derived from the text below, explaining the breakdown structure.

Table 6 Overview of the break down of the definitions

Category	Cost driver
Volume flexibility	Over demand
	Under demand
	Capacity expansion

[155] Kaplow, I. (1989)
[156] Maskell, B. (1989)

Mix flexibility	Merger of several lines
	Change over time
New product flexibility	Capacity adjustment
	Ramp up
Delivery time flexibility	Reduced non-value time
	Loss of revenue

6.1.1 Volume flexibility

Volume flexibility means that the output can change even when disregarding seasonal fluctuations and is mainly a capacity management problem[157]. Volume changes also must be implemented without effecting efficiency or quality[158]. We define *volume flexibility* as the ability to transform the output according to the varying demands over time.

In a conventional production system it is difficult and time consuming to do alterations, in order to change the capacity of the system. DAS enables companies to meet changes in demand to a low cost. It is easy to expand the capacity of DAS, because a rebuilding of the system, or rather adding of workstations, can be done without any longer production stops. The cost of meeting the demand includes not only the cost of rebuilding the manufacturing system, but also the cost of having over or under capacity.

Volume flexibility is assessed using the following three cost drivers:

6.1.1.1 Under demand

Under demand can be explained as the situation where market demand is less than the capacity of the installed manufacturing system.[159] This generates costs. Usually plants have some kind of excess capacity compared to the demand to be able to respond fast to upward fluctuations. Demand is thereby in this paper treated equivalent to the parts that are actually being made. The excess capacity can sometimes be rescheduled for another use, which generate costs although these should be lower than non-usage of the overcapacity for the rescheduling to be done. The costs of under demand are therefore the cost of having capacity that is not fully utilised. Revised formula as defined by Pyoun et al. (1995) with our own denotations[160]:

$$C_{UD} = (PC(1 - DOC) - demand)(1 - OC_T)\delta(\mathrm{C_{PC}} - \mathrm{C_M})\mathrm{T_{UD}} + C_{UDP} \quad [9]$$

C_{UD} = Cost of under demand
PC = Plant capacity
DOC = Desired over capacity
demand = Units requested by the market

[157] Chambers (1992), p. 289
[158] Suarez et al. (1995)
[159] Pyoun, Y.S., Choi, B.K, Park, J.C (1995), p. 274
[160] Pyoun et al. (1995), p. 273-274

OC_T = Percentage of over capacity transfer for another use
δ = 1 if ((1-DOC)PC – demand)(1-C_T)≥0, else δ = 0 referring to a situation when no under demand exists.
C_{PC} = Total cost invested in part
C_M = Material cost
T_{UD} = time of under demand
C_{UDP} = Cost of planning (cost of rescheduling / transferring capacity)

Having excess capacity generates a cost that can be calculated using the following formula:

$$C_{DOC} = DOC \cdot PC(C_{PC} - C_M) \qquad [10]$$

C_{DOC} = Cost of desirable over capacity
PC = Plant capacity
C_{PC} = Total cost invested in part
C_M = Material cost

6.1.1.2 Over demand

Over demand can be explained as the situation where market demand exceeds the capacity of the installed manufacturing system[161].

This also generates costs since it means that orders are missed and the potential revenue thereby is not fully utilised. The costs are therefore lost sales or subcontract production costs.[162]

$$C_{OD} = \tau \cdot \varepsilon(demand - PC) \cdot T_{OD} \qquad [11]$$

C_{OD} = Cost of over demand
τ = 1 if (demand – PC)>0, else τ = 0 referring to a situation when no over demand exists.
ε = Average extra cost of production exceeding PC, subcontract production or lost sales depending on strategy
PC = Plant capacity
T_{OD} = Time of over demand

6.1.1.3 Capacity expansion

Capacity expansion is the cost associated with the rebuilding of the existing manufacturing system. The cost of expanding capacity is defined as the cost of production stop and the cost of incremental investments illustrated in Eq. [12].

Expanding capacity is often a result of over demand. Even if there is a clear relationship between over demand and capacity expansion, we find it important to handle these separately. Expanding capacity can be done without meeting any over demand, like in the case of introducing new products. Inversely, companies can face

161 Pyoun, Y.S., Choi, B.K, Park, J.C (1995), p. 274
162 Pyoun et al. (1995), p. 274

over demand without taking any action, expanding the capacity in the manufacturing system being too costly compared to the possible increase in profit.

The cost of a production stop involves factors as decreased production, over time, loss of customers, and loss of orders (revenue). We will be conducting the cost of production stop under two different assumptions. The first assumption is that the stop is planned ahead and that precautions have been taken for all orders to be met. The calculation of this cost is done using Eq. [13]. The second assumption is that all orders cannot be met, which leads to loss of revenue. To calculate the cost of the loss, the equation for over demand Eq. [11] will be used in addition to the cost of production stop [13]. The cost of running the plant without producing is calculated by subtracting the cost of material from the total cost normally invested in a part since most of these costs will still remain during a production stop.

$$C_{CE} = C_{PS} + C_I \qquad [12]$$

$$C_{PS} = (C_{PC} - C_M) \cdot R_p \cdot T_{PS} + C_{PSP} \qquad [13]$$

C_{CE} = Cost of capacity expansion
C_{PS} = Cost of production stop
C_I = Cost of incremental investment
C_{PC} = Total cost invested in part
C_M = Material cost
R_P = Production rate
T_{PS} = Time of production stop
C_{PSP} = Cost for planning, overtime, increased overhead

6.1.2 Mix flexibility

The term can be defined as the number of products that can be produced by a system at any given time[163].

Having many different products in one line at the same time leads to several advantages. Producing several products within the same system simultaneously can lead to high capacity utilisation and the cost of capacity thereby decreases.

Mix flexibility is assessed using the following two cost drivers:

6.1.2.1 Merger of several lines

Since DAS has the ability to handle the flow of many different products and product variations simultaneously the need for multiple production lines decreases. This gives the possibility to merge lines into fewer ones thus increasing the utilisation of the plant’s resources. This means that single operations similar in different lines can be shared between lines and even in extreme cases entire lines can be shut down. Machines can thereby be sold and more floor space can be cleared. The event of closing one or several lines down will also have effects on the organisation. If

[163] Suarez et al. (1995)

production can be made substantially more efficient the possibility of decreasing the staff arises.

The first step in deciding the effects of merger of lines is to calculate the capacity utilisation in the existing lines. This can be done using Eq. [5]. To target the actual cost savings of merger of lines the savings in form of reduced machines, floor space and labour must be calculated.

The machine cost savings are composed of the capital cost related to machines and the cost of running them in production. The total cost is a summation of the cost associated with each machine.

$$C_{MM} = \sum_{i=1}^{n} C_{CMi} \cdot (AOHC_{Mi} + 1) \qquad [14]$$

C_{MM} = Costs associated with machines
C_{CM} = Capital cost associated to machine
$AOHC_{M}$ = Allocated overhead cost associated to machine

The floor space cost saving is calculated by multiplying cleared area with the cost per square metre. This saving is only applicable if the excess space can be disposed of.

$$C_{FS} = FS \cdot C_{FSSM} \qquad [15]$$

C_{FS} = Cost of floor space cleared
FS = Floor space cleared
C_{FSSM} = Cost of floor space per area

The labour cost saving is calculated as an estimate of what savings can be derived from laying of personnel, assessing the costs associated with wages paid.

$$C_{L} = \sum_{i=1}^{n} T_{Li} \cdot W_{Li} \cdot (AOHC_{Li} + 1) \qquad [16]$$

C_{L} = Cost of saved labour
T_{L} = Hours saved
W_{L}= Wage paid to staff member
$AOHC_{L}$ = Allocated overhead cost associated to staff member

6.1.2.2 Change over time

Change over time is the time it takes to change between different products in the manufacturing system. With DAS there is no time required for reorganisation of the flow when changing between products. When having several products in the same line, it is important that the switch between the products can be done quickly and at a low cost. Depending on the existing system the cost of change over will differ. Factors affecting the cost of change over include rescheduling the flow, clearance costs, setup-times, etc. The cost of change over time can be calculated as:

$$C_{CO} = C_{SCO} \cdot N_{CO} \qquad [17]$$

C_{CO} = Total cost of change over
C_{SCO} = Cost of single change over
N_{CO} = Number of changeovers

If the number of changeovers cannot be attained from the company for any reason an approximation can be made based on the different output percentages of the products/variants[164]. The formula is based on the extreme case of production without any planning involved regarding which product to produce next.

$$N_{CO} = (1 - \sum_{i=1}^{n} x_i^2) \frac{output}{batchsize} \qquad [18]$$

N_{CO} = Number of changeovers
X_i = Percentage of total output for product *i*

6.1.3 New product flexibility

New product flexibility is defined as the ability of the manufacturing system to produce new products.[165]

A system that easily incorporates new products not only render possible future cost savings but also involves the possibility to a quick market response. When investing in a new manufacturing system it is important to consider how often new products are introduced or will be introduced in the future. The total cost of introducing new products by the use of the following equation:

$$C_{NP} = C_{ANP} \cdot N_{NP} \qquad [19]$$

C_{NP} = Total cost of new product introduction
C_{ANP} = Cost on average for a new product introduction
N_{NP} = Number of new product introductions

It should be mentioned that these figures might be extra difficult to come by since they are hard to track and many companies therefore cannot supply explicit numbers.

N*ew product flexibility* is assessed using the following three cost drivers:

6.1.3.1 Capacity adjustment

The cost linked to the adjustment of capacity to the new product depends on the existing line. When introducing new products different scenarios can be identified, namely building a new line, expanding, or rebuilding an existing line.

[164] David Nyberg, (2004) Contact by mail, 2004.04.13
[165] Olhager, West (2002), p. 66

The cost of adjusting capacity is, like capacity expansion, defined as the cost of production stop and the cost of incremental investments according to Eq [12]. Variables such as time of production stop, planning cost and cost of incremental investment specifically associated with the introduction of new products needs to be identified.

6.1.3.2 Ramp-up

One part in introducing new products is the production ramp-up. During the ramp-up the capacity utilisation is lower than normal. The ramp of a new product can impact the existing products in the system. With DAS pilot runs and ramp-up can be tested off line through virtual link to quicker achieve normal delivery performance. Concurrent training for operators can be done with the system. This lowers the time needed for ramp-up.

The reason why capacity utilisation is generally lower during ramp-up is due to trouble-shooting machinery, train personnel, learning curves, controlling the flow of products and so forth. The costs of capacity utilisation can be calculated by taking into account the extra cost associated with producing the same output as long as all orders still can be met.

$$C_{RU} = ((1 - U_{RU}) \cdot T_{RU} \cdot output \cdot (C_{PC} - C_M) + C_{PRU}) \cdot N_{RU} \qquad [20]$$

C_{RU} = Cost of ramp-up utilisation
U_{RU} = Utilisation during ramp-up
T_{RU} = Time of ramp-up
output = Number of parts produced
C_{PC} = Total cost invested in a part
C_M = Material cost
C_{PRU} = Cost for planning, overtime and increased overhead
N_{RU} = Number of ramp-ups

6.1.4 Delivery time flexibility

Delivery time flexibility is the ability to respond to short-term fluctuations in demand[166]. This was formerly something that customers were willing to pay extra for but this is not the case in many markets today. Short delivery times are instead taken for granted.[167] The connection to mix flexibility is evident when it comes to the ability to change between different products if the orders call for it.[168] Having many different products within the same system at the same time leads to the ability to vary the volume within the product mix without thereby affecting the total output. This has impact on the delivery speed.

[166] Chambers, (1992), p. 290
[167] Olhager & West (2002), p. 64
[168] Olhager & West (2002), p. 71

Delivery time flexibility is assessed using the following two cost drivers:

6.1.4.1 Reduced non-value time

The base for shorter lead-time is that the non-value adding time is decreased to a bare minimum. This mainly has effects on costs of WIP and can be calculated by the use of Eq. [6] and the internal interest rate of the company denoted *i*. The material cost is treated separately from the other expenses depending on kitting and layout of the plant at hand.

The decrease in non-value adding time leads to cost savings from reduced time of labour. This cost of saved labour associated to shorter MLT, C_{LMLT}, is calculated using Eq. [16] by assessing the hours saved on labour, T_{LMLT}.

6.1.4.2 Loss of revenue

If loss of orders occurs simply because of a too long delivery time the loss of this revenue can be identified as a potential cost saving. It should be noted that compliance with demands from the market when it comes to delivery time is a prerequisite for even competing on some markets and the importance of it can thereby not be stressed enough. Added to the orders lost because of the delivery time not being short enough are orders lost due to the inability to change between different products according to the discussion on mix flexibility and delivery time flexibility above. Appreciating the number of less sold products related to the extent of delivery time, N_{LD}, and the cost of a single less sold product, C_{LD}, assess the loss of revenue by simply multiplying them.

6.2 Quality related savings

Table 7 is a summary of the quality aspects that are identified to be affected by DAS. The table is a modification of a table by Dale and Wan (2002)[169]. The identified aspects are put into formulas, most of them short and easy whereas the problem is gathering the empirical material needed to identify the different variables.

The costs incurred because of external failures will however not be addressed. Also the costs because of appraisal will not be addressed. This is because the time spent on testing is assumed to be unaffected with an introduction of DAS, although the number of repairs and failures will decrease.

Table 7 Overview of the aspects affected by the DAS-system

Cost categories	Cost elements	Chapter below dealing with this cost element
Prevention	Quality planning	Time spent on prevention
	Design and development of equipment	Quality system
	Quality training	Time spent on prevention
	Quality auditing	Time spent on prevention

[169] Dale, Wan (2002), p. 106

	Reporting of quality data	Documentation
	Quality improvement programmes	Time spent on prevention
Internal failure	Scrap	Repairs and failures
	Replacement, rework and repair	Repairs and failures
	Troubleshooting	Time spent on failure
	Reinspection and testing	Repairs and failures

6.2.1 Conformance – Prevention

Conformance – Prevention is assessed using the following three cost drivers:

6.2.1.1 Quality system

DAS can be regarded as a quality system in itself and therefore additional investments in quality systems within the assembly line are not necessary. These cost savings are referred to as *Cost of Quality System,* C_{QS}. This equals the expenditures on quality systems.

6.2.1.2 Time spent on prevention

The built in software allows the system to continuously identify quality problems. Are any reoccurring problems recorded the system will automatically send test instructions and units to be tested to certain workstations by rearranging information and material flow, thereby temporarily converting these into test stations. Therefore the time normally spent manually scheduling the quality planning is reduced.

Time is normally also spent on quality related training, quality auditing and various quality improvement programs. The total time spent on these activities incurs a cost referred to as *Cost of time spent on prevention,* C_{PR}, calculated using the following equation.

$$C_{PR} = \sum_{i=1}^{n} T_{PRi} \cdot W_{Li} \cdot (AOHC_{Li} + 1) \qquad [21]$$

C_{PR} = Cost of time spent on prevention
T_{PR} = Time spent on prevention
W_L = Wage paid to staff member
$AOHC_L$ = Allocated overhead cost associated to staff member

6.2.1.3 Documentation

The automatic generation of production information lets the employees focus on value-adding operations instead of collecting and compiling this kind of information. The cost saving incurred from eliminating this non-value-adding time is calculated using the following equation:

$$C_D = \sum_{i=1}^{n} T_{Di} \cdot W_{Li} \cdot (AOHC_{Li} + 1) \qquad [22]$$

C_D = Cost of time spent on documentation
T_D = Time spent on documentation
W_L = Wage paid to staff member
$AOHC_L$ = Allocated overhead cost associated to staff member

6.2.2 Non-conformance – Internal

Non- conformance – Internal is assessed using the following two cost drivers:

6.2.2.1 Repairs and failures

DAS automatically directs the product to the correct workstation. The order in which the product is assembled is set within the software, which then controls the material flow through the assembly line. Information about the product arriving at the workstation and instruction notes are presented automatically on the screen. This information is derived from the *Bill of Material* and other product specific information logged within the database. The product cannot be checked-out to proceed to the next workstation until all specified assembly steps have been conducted.

Aspects such as software controlled material flow and coordinated operation instructions leads to a process that proactively limits the possibility of assembly work being wrongly conducted. This is especially true when introducing new products before the process has been tuned in. The continuous mapping of the information allows problems with quality to be traced as soon as they occur and countermeasures can thereby automatically be initiated. The mapping also provides the possibility of tracing a certain non-conforming products route through the system, identifying at what specific workstation the failure occurred.

Because of the different aspects of DAS stated above the number of repairs and failures are reduced compared to using a traditional assembly line. This leads to direct cost savings.

The cost savings incurred by lower repair rate is referred to as *Cost of repairs*, C_R. These can be calculated using the following formula.

$$C_R = (H \cdot W_R \cdot (AOHC_R + 1) + C_{RM}) \cdot r \cdot output \qquad [23]$$

C_R = Cost of repairs
H = Time spent on repairing one unit
W_R = Wage paid to staff member working with repairs
$AOHC_R$ = Allocated overhead cost associated to staff member working with repairs
C_{RM} = Cost of material scrapped
r = Rate of repairs
output = Number of parts produced

Those products that cannot be repaired are scrapped. These failures incur a cost referred to as *Cost of failures*, C_{FAIL}, and this cost is calculated using Eq. [24.1]. The formula takes into account the effect of having test stations along the line and where in the line the non-conforming product is identified, hence the summation where the denotation [i] refers to the specific test station. The cost of the product is then assumed to be proportional to the time spent in production, T_C. The shorter Eq. [24.3] refers to the case with a single test station at the end of the line. In both cases it is assumed that all of the material put in is scrapped.

$$C_{FAIL} = \sum_{i=1}^{n} (C_{PC\,i} \cdot \frac{T_{Ci}}{MLT}) \cdot q_i \cdot output \qquad [24.1]$$

$$C_{FAIL} = C_{PC} \cdot q \cdot output \qquad [24.2]$$

C_{FAIL} = Cost of failures
C_{PC} = Total cost invested in part
T_C = Time spent in production
MLT = Mean lead time
q = Units taken out of production
output = Number of parts produced

6.2.2.2 Time spent on failure

When non-conforming items occur in the system the source of the problems needs to be identified. With a reduced number of non-conforming items the total time of troubleshooting is decreased and hence the *Cost of time spent on failure*, C_F. Similar to the calculation of cost of time spent on prevention this can be calculated as the total time spent times wages and allocated overhead cost.

$$C_F = \sum_{i=1}^{n} T_{Fi} \cdot W_{Li} \cdot (AOHC_{Li} + 1) \qquad [25]$$

C_F = Cost of time spent on failure
T_F = Time spent on failure
W_L = Wage paid to staff member
$AOHC_L$ = Allocated overhead cost associated to staff member

7 Empirical study

The two case study companies and the gathered essential information from them, is presented. The information has been collected based on the interview guide found in Appendix 4.

7.1 Company Y

Company Y is part of a major international corporation manufacturing a number of products to many different markets. At the plant at hand there are three assembly lines with one line manager each and totally 84 staff members working in the assembly. The organisation is rather hierarchal, with several levels of managers. The assembly process is strictly manual and most of the workers are capable to perform all the different operations. The company manufactures electronic products small enough to be easily fitted in the palm of ones hand. The technological content is high. The company points out the importance of high quality and reliable production. The product range is broad and is comprised of 29 base types and 308 different product numbers. All of these products are similar in design, size and prerequisites for assembling. The products are shipped and sold to retailers all over the world. In Figure 10 a schematic overview of the assembly is presented:

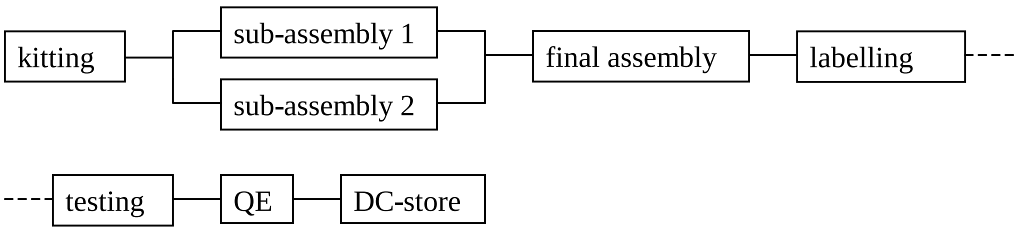


Figure 10 Flowchart of the major steps within the assembly at company Y

7.2 Company Z

Company Z is a manufacturing company that handle the entire process from transforming raw material until finished product. The company has 160 employees, of whom 8 are working in the assembly. There are four lines in the assembly. The assembly is to a high extent automatised, but some operations are manual. The products made are simple and small and can almost be fitted into the palm of ones hand. The level of technology is low. The number of different variations is a total of 62, and the introductions of new products are low. The output of the plant is high, reaching 100 thousand units per months. The company is part of a group that is the world’s largest supplier of systems to the manufacturers in the industry. The product represents an essential part in machines sold and it is therefore important for the company that the products are of a high quality. In Figure 11 a schematic overview of the assembly is presented:

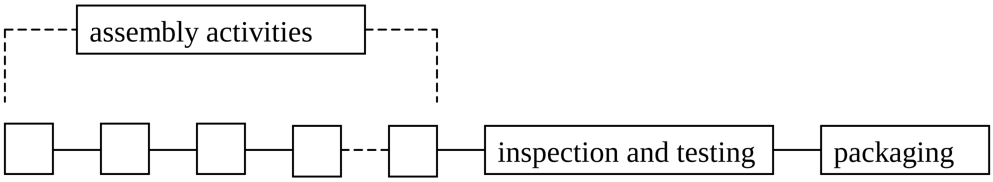


Figure 11 Flowchart of the major steps within the assembly at company Z

7.3 Explanation of data for the two companies and for DAS

The following explanations refer to Table 8. *Data for the case companies and DAS,*. Most of the variables are described in order to get a guide to the table as understandable as possible. The explanations start with case company Y and then the explanations referring to case company Z are somewhat shorter since references are made to explanations used on case company Y.

7.3.1 Y - Effects of having a manual assembly line

7.3.1.1 General

- The **initial investment for DAS** is estimated by FlexLink to be 1.000.000 S$. This estimation can be questioned since pricing depends on design and configuration and this has not yet been done when this is written. Instead the figure is derived from experience from proceeding, similar cases combined with the information at hand in this certain case.
- The **difference in operating cost** between the present production system and DAS is set to be zero. This is unlikely but it is hard to estimate and should in this certain case not affect the calculations to any great extend. The operating costs might be higher with DAS since factors such as maintenance and power supply definitely will increase whereas these kinds of costs with the present system are negligible since it is completely manual.
- The number of staff (**work centres**) will be kept at 84. Since the only factor that have been changed influencing this, of failures, set-up time and operation time, is set-up time, and that this does not affect it to a large enough extent, the number of employees is constant even if PC has been affected somewhat.
- **Shifts per week**, **hours per shift** and **parts made** are set to be unaffected. This since an introduction will lead to no rearrangements in working hours and parts made and then sold. All these figures represent the initial situation at the company.
- The **set up time** will lessen significantly going from 20 minutes (0.33 hours) to 5 minute mainly because the operators do not need to leave their workstations to attain the kitted material. Instead the material is automatically transported to the workstation by DAS. The 20 minutes are derived from observations and basic clocking of certain steps whereas the 5 minutes are an approximation based on observations regarding the possibilities presented by DAS.
- **Batch size** and **operation time** will not be affected. Of course it could be argued that the optimal batch size might not be 100 and that optimal batch size with the present system compared to DAS might not be the same. This

however needs further investigation and is not dealt with since any calculations and estimates would need more of a technical analysis of the production system.

- When introducing DAS the rate of repairs normally decrease but nothing is said about the number of **units taken out of production**. Therefore this figure remains unaffected by an introduction of DAS.
- The **total cost invested in part** can be calculated by using Equation 7 but the figure of 50.18 S$ comes directly from the company and is stated to be representative for most of their products. If the investment would turn out to be successful this would lead to a decrease in total cost invested in part reflecting lower total cost. However in these calculations the cost will remain unchanged because of two reasons. Firstly because of the fact that it is near to impossible to estimate a new cost since it depends on the outcome of the calculation it self. Secondly the decrease is due to savings that are taken into account in the calculation.
- Sustaining the same batch size the **MLT** will not decrease to any major extent. The difference will be a few hours and this is due to shortened set-up time as well as the decrease in non-operating time. Hence the MLT for DAS is estimated to be 63 hours. The hours are made up by the operating time times the batch size. Added to this is also a waiting period of 10 hours for glue hardening and the new set-up time.
- **Wages for staff members** are divided into two different categories, the first one at a level of 5 S$ referring to the workers whereas the 20 S$ to line managers.
- The **AOHC wages** is calculated by subtracting scrap, material and other fixed costs from production thereby creating a ratio that allocates overhead.
- Similar to the total cost invested in part the **sales price** was also provided by the company and is 376 S$.
- A major part of the cost invested in part comes from **material cost** which is calculated by the company to be 32 S$.
- The company states that they are using an internal **interest rate** matching their WACC at 6 %.
- The **number of weeks per year** used is not in any way company specific but a common generalisation of the number of weeks usually used and therefore also used by the authors.

7.3.1.2 Volume flexibility

- No information on changes in **demand** has been attained and demand is therefore set to equal the number of parts made. This zeros out any costs of over or under demand. The situation is set to be the same after having introduced DAS. The demand not changing also leads to a situation where there is no need to further investigate information on factors affecting the volume flexibility. Nevertheless some comments will be added on specific factors.
- The **desirable over capacity** is set to be zero since they are meeting all of their orders by working overtime instead of hiring additional staff. This is due to the fact that wages are low, and that hiring and firing is managed quite easily in the region.

- There is no **time of production stop** when adjusting the capacity of the plant since it is totally manual. According to information from FlexLink an adjustment with DAS would normally incur a production stop of 5-30 minutes and the mean value 17.5 minutes is used.
- Because of the prerequisites of the plant there are no **incremental investments** of interest.

7.3.1.3 Mix flexibility

- Since the plant is completely manual there is no **capital cost associated to machines** and thereby of course not any **AOHC machine** is applicable.
- Applying DAS at case company Y would lead to the three lines being merged to one. Such a merger would lead to a situation when two of the three line managers can be made redundant resulting in 88 **hours saved per week**. The line managers' main tasks are to assign work orders to the staff as well as collecting and summarising production data. DAS will handle this automatically.
- A merger also leads to **floor space cleared**, estimated by FlexLink to be 100 square meters. The weekly cost per square meter is 3.3 S$. The company rent the facilities and so this would render a cost saving.
- There is no **cost of change over** since the changeovers only occur during a flip of a second in the mind of the staff because no machines need to be reset or altered in any way. The time between two different products is therefore no longer than the usual set up time. Therefore the **number of changeovers** has not been measured or estimated.

7.3.1.4 New product flexibility

- The new product flexibility is dependent on the **number of new products** and the **cost of new products**. The cost of new products is immensely difficult to attain although the number of new products is a rather straightforward figure and is calculated to be 1.28 products on a weekly basis. This figure is derived from the yearly number of new products being 60 and the year being comprised of 47 active weeks. Still the lack of information on the cost of a new product draws to the necessity of investigating new product flexibility using the approach of looking into the effects of capacity adjustments and ramp-up.
- There is no **time of production stops** and there are no **incremental investments** for the same reasons as stated above, due to the assembly being completely manual. The **planning cost** associated with the introduction spans many levels and has not been possible to attain. However the DAS-concept leads to a production stop when introducing new products. This is stated to be approximately 0.3 hours according to the experience of prior DAS implementations.
- Ramp-up is associated with a lower capacity utilisation that itself is dependent on four different variables. Although there are new product introductions and possibly these are connected to a **number of ramp-ups** with the effect of a **ramp-up utilisation** during a certain **ramp-up time** all these figures have not been possible to estimate. The number of ramp-ups per week and the ramp-up time is estimated to be 0.0426 and 528 hours respectively. These figures are derived from the fact that on a yearly basis

there are two major introductions of new products leading to 0.0426 when divided by 47. These introductions are estimated to last for one month of work being equal to 22 days. Multiplying 22 days with 24 hours leads to 528 hours.

7.3.1.5 Delivery time flexibility

- The hours saved due to delivery time flexibility are derived from any change of the number of work centers as described above and since this figure is kept at 84 the **hours saved per week** equals zero.
- The **number of less sold products** refers to the potential of increasing incoming orders should the delivery time be shorter. The delivery time is closely connected the MLT. The company claims that incoming orders would not increase should the delivery time be shorter and so the number of less sold products equals zero in both columns. Hence the cost of single less sold product has not been investigated.

7.3.1.6 Conformance, Prevention

- Although it is possible there are **costs of quality systems** at hand and that these costs would not be necessary if DAS was used any estimates could not be attained.
- The **time spent on prevention** was not possible to attain. Most there are costs incurred because of prevention work but the company do not keep track of any such costs.
- The **time spent on documentation** is stated to be less than 1 % of total worked hours and is therefore estimated to be about 20 hours weekly. This kind of documentation will be handled automatically by DAS but is now done by non-qualified workers. Less time spent on documentation within the line leads to a corresponding decrease in operating time but compared to total weekly operating time 20 hours are regarded as negligible. The same argumentation can be used to disregard the effects of other saved work hours as long as the savings are at a reasonable level and are significantly smaller than total operating time.

7.3.1.7 Non-conformance, Internal

- According to the company **time spent on repairs** of a single part varies from 30 minutes to 45 minutes. The mean time is therefore set to 0.625 hours and there are no indications that this would change with DAS.
- It has not been possible to retrieve information on the **cost of material scrapped and replaced**. Hence both with the present system and with DAS the figure equals zero.
- The **number of repairs** was stated to be between 5-10 % and the percentage by which these can be decreased is 30-60 % according to prior experiences. Using the mean value of them both gives us the number of 4.13 %.
- Since failures occur it is reasonable to believe that reasons for failures are tracked. However, this **time spent on failure** has not been possible to derive since the company does not have this information and a measuring of this time would be to time consuming. In both cases the figure therefore zeros out.

7.3.2 Z - Effects of having a highly automated line

Some explanations rely on things said in the explanations on case company Y.

7.3.2.1 General

- As with case company Y the **initial investment for DAS** is an estimate based on the information at hand.
- Although unlikely the **difference in operating cost** between the present situation and with DAS is set to be zero. This is mainly because of lack of information.
- With the case of company Z the number of **work centres** do not refer to the number of staff within the line as with case company Y. Instead it refers to the number of lines. To balance the calculations this figure is set to be four with DAS as well and should be seen as a way to handle the calculations rather than a description of the layout. Should a merger be possible and cost efficient of course four lines would not be the case.
- **Shifts per week**, **hours per shift** and **parts made** are also in this case set to be unaffected for reasons stated above.
- The **set up time** is 12 hours and incurs a cost of 150 S$ consisting purely of labour cost. This set up time would not decrease by using the DAS concept since it is due to preparing the machines and not associated with rearranging the flow.
- The standard **batch size** is 30.000 parts and this will not be affected by DAS. Neither is the **operation time** equalling 0.015 hours affected. Referring to the 30.000 parts as batch size might be misleading. Instead the figure 30.000 describes the number of parts produced between the changeovers. Instead of batched production the production is actually better described as flow production since the individual parts continue to the next operation before all have passed a certain operation. The set up time could then be regarded as change over time (see **change over time** below).
- The **rate of failures** is less than 1 %, here set to 0.8 % remaining unchanged with DAS.
- The **total cost invested in part** is stated to be 2.3 S$. In accordance with the discussion on total cost invested in part at case company Y the cost remain unchanged.
- The MLT is said to be 72 hours but at the same time the company states that this sometimes might be significantly less. Observations have somewhat helped establishing an understanding of this figure and the MLT is therefore set to 72 hours. A calculation or estimation to measure MLT as would it be with DAS has not been successful and so the figure of 72 hours is kept. This is consistent with the unchanged set up and operation time. Although reduced non working time would decrease the MLT this is not assessed since information is inadequate and estimates would be mere guesses.
- The **wages for staff members** are split into costs associated with skilled and non-skilled operators and are 5 S$ and 20 S$ respectively.
- The **AOHC wages** is stated to be 0 % since this is included in the wages for staff members already.
- The **sales price** was provided by the company and is 3.5 S$.

- The cost of the product includes the **material cost** in this case being only 0.06 S$ according to the company.
- The case study company has classified the **interest rate** as confidential. We will use an interest rate of 10 % in our calculations. It is our experience that a normal level of the internal interest rate is higher being derived from alternative options to invest and by regarding the risk of the current investment.
- The **number of weeks per year** used is not company specific and is set to 47 week as with the case company Y.

7.3.2.2 Volume flexibility

- The present **demand** is 16.000 parts per week equal to the number of parts made. There is no information on whether this will change or not and so demand is set to be 16.000 parts. As with case company Y this leads to no effects from over demand whereas they suffer from costs due to under demand. This under demand is due to excessive machine capacity and so would not be adjusted because of DAS.
- The utilisation is around 70 % but the preferred utilisation is said to be 90 % leading to a **desirable over capacity** of 10 %.
- The capacity is dedicated and specialised to this certain kind of production and so the **percentage of over capacity transferred for another use** is set to be zero percent. Thereby no efforts have been made to try and attain a figure on the **rescheduling cost**.
- As stated above the variables connected to **over demand** will not be addressed because of the utilisation rate of 70 %.

7.3.2.3 Mix flexibility

- The **capital cost associated to machine** and the **AOHC machine** has not been attained because of two reasons. Firstly a merger of lines would not lead to any possibilities to share machine capacity among products previously produced in different lines. Secondly it was not possible for the company to supply us with the information without extensive investigations.
- A merger of lines would not lead to less work needed to be conducted. This because of the prerequisites stated above about no possibility to reduce machines and thereby workers connected to certain machines. Also there are no line managers in excess. Hence **hours saved per week** equals zero.
- The **cost of floor space** was not attained directly from the company since it is internally calculated only as an overhead cost. It is therefore set as the same as company Y since it is judged by the authors that this should not differ much.
- The **floor space cleared** was attained by first identifying the floor space in use with the present layout. To estimate a figure for DAS this was then multiplied by 30 % corresponding to the information from previous cases. This floor space might be possible to rent to another company thereby generating a cost saving.
- According to the discussion above on set up time the **change over time** is 12 hours incurring a **cost of change over** of 150 S$. Consistently with the discussion this will not change with DAS. The number of change overs is

derived from information about the monthly number of change over being 2 to 3. The average divided by four weeks a month gives a weekly figure of 0.625.

7.3.2.4 New product flexibility

- Company Z introduces a new product approximately once every five years. The factors associated with **new product flexibility** will thereby not be considered.

7.3.2.5 Delivery time flexibility

- The **hours saved per week** associated to delivery time flexibility depends on decrease in set up time, operating time and rate of failures. These variables not changing with DAS leads to no work hours being saved.
- Reducing the delivery time would not increase the company's possibility to gain orders, accordingly the **number of less sold products** because of the delivery time closely connected to MLT zeros out. Because of this the **cost of single less sold product** has not been investigated. This is applicable in both cases.

7.3.2.6 Conformance, Prevention

- Information on expenditures on the kind of quality systems DAS is equipped with has not been able to attain. The **cost of quality system** is therefore set to zero.
- **Time spent on prevention** with DAS might differ from the present situation but no information has been possible to attain.
- **The time spent on documentation** equals 3 % of work hours. Calculating this on a weekly basis applying the shifts per week, hours per shift with eight staff members working every shift gives the figure of 20 hours. This documentation will be handled automatically within DAS but is now done by qualified workers.

7.3.2.7 Non-conformance, Internal

- The time spent on repairs as well as the cost of material scrapped and replaced has not been attained.
- The **rate of repairs** was set 0.5 %. We use 0.5 % and calculate that it would decrease by 45 %, this being the average decrease in number of repairs with DAS, giving us the number of 2.75 %.
- Any figure on **time spent on failure** has not been able to attain.

7.4 Data for the case companies and DAS

The following table summarises the empirical material as presented above.

Table 8 Data for the case companies and DAS

N.A. = Not applicable
I.M. = Information missing

Initial investment for DAS	1000000		800000	
Difference in operating cost (present - DAS)	I.M.		I.M.	

General	Y	DAS	Z	DAS
Work centres	84	84	4	4
Shifts per week	5	5	10	10
Hours per shift	8.8	8.8	8.63	8.63
Parts made	8500	8500	16000	16000
Set up time	0.33	0.083	12(150$)	12(150$)
Batch size	100	100	30.000	30.000
Operation time	0.53	0.53	0.015	0.015
Rate of failures	2.00 %	2.00 %	< 1 %(0.8 %)	< 1 %(0.8 %)
Total cost invested in part (according to company)	50.18	50.18	2.3	2.3
MLT	72	64	72	72
Wages for staff members 1	5	5	6	6
Wages for staff members 2	20	20	12	12
AOHC wages	60.00 %	60.00 %	Included above	Included above
Sales price	376	376	3.50	3.50
Material cost	32	32	0.06	0.06
Interest rate	6.00 %	6.00 %	10.00 %	10.00 %
Number of weeks per year	47	47	47	47

Volume flexibility				
Demand	8500	8500	16000	16000
Desirable over capacity	0.00 %	0.00 %	10.00 %	10.00 %
Percentage of over capacity Transferred for another use	0.00 %	0.00 %	0.00 %	0.00 %
Rescheduling cost	0	0	0	0
Time of under demand	0	0	1	1
Average extra cost of production exceeding PC, subcontract production or lost sales depending on profit	0	0	0	0
Time of over demand	0	0	0	0
Time of production stop	N.A.	0.292	0	0.292
Planning cost	I.M.	I.M.	I.M.	I.M.
Cost of incremental investment	N.A.	N.A.	I.M.	I.M.

Mix flexibility				
Capital cost associated to machine	N.A.	N.A.	I.M.	I.M.
AOHC machine	N.A.	N.A.	I.M.	I.M.
Hours saved per week, 1	N.A.	0	N.A.	0
Hours saved per week, 2	N.A.	88	N.A.	0
Cost of floor space	3.3	3.3	3.3	3.3
Floor space cleared	N.A.	100	N.A.	111
Cost of change over	0	0	150	150
Number of change over	I.M.	I.M.	0.625	0.625
New product flexibility				
Number of new products	1.28	1.28	0.00385	0.00385
Cost of new product	I.M.	I.M.	N.A.	N.A.
Time of production stop	N.A.	0.30	N.A.	N.A.
Planning cost	N.A.	N.A.	N.A.	N.A.
Cost of incremental investment	0	0	N.A.	N.A.
Ramp-up utilisation	I.M.	I.M.	N.A.	N.A.
Ramp-up time	528	528	N.A.	N.A.
Number of ramp-ups	0.0426	0.0426	N.A.	N.A.
Planning cost	I.M.	I.M.	N.A.	N.A.
Delivery time flexibility				
Hours saved per week, 1	N.A.	0	N.A.	0
Hours saved per week, 2	N.A.	0	N.A.	0
Number of less sold products	N.A.	N.A.	N.A.	N.A.
Cost of single less sold product	N.A.	N.A.	N.A.	N.A.
Conformance, Prevention				
Cost of quality system	I.M.	I.M.	I.M.	I.M.
Time spent on prevention	I.M.	I.M.	I.M.	I.M.
Time spent on documentation	20	0	20	0
Non-conformance, Internal				
Time spent on repairs	0.625	0.625	I.M.	I.M.
Cost of material scrapped and replaced	I.M.	I.M.	I.M.	I.M.
Rate of repairs	7.50 %	4.13 %	0.5 %	0.22 %
Time spent on failure	I.M.	I.M.	I.M.	I.M.

8 Analysis

The theoretical framework and the empirical material are connected and create the base for the analysis. The analysis is divided into three parts. In the first part, calculations on the case companies are made and the results are discussed. The second part discusses the prerequisites for DAS and where the system is suitable. This is made to get a better understanding of the results at the case companies and to discuss in what contexts DAS is suitable. In the last part of the analysis the theoretical interpretation and development of the model is discussed. The aim is to highlight the strengths and weaknesses of the model and to discuss the model's usefulness.

8.1 Calculation and interpretation of results

Calculations on the two different case companies are not divided into the same steps due to the prerequisites of the different companies explained below. The calculations are presented in *Appendix 2*. This part of the analysis is divided into the following subsections:

- Basic calculations are made and briefly commented.
- Assumptions are made to further expand and incorporate factors affecting the calculations. These assumptions on factors where information is missing are derived from experience from observing the processes and from discussions with case company and FlexLink representatives.
- Some of the figures supplied by the companies are questioned. The reason for doing this is that we doubt the accuracy of certain figures. We will identify figures to alter thereby identifying different scenarios and hence visualising sensitive areas within the model. This is a further development of the assumptions made previously.
- The discussion on the results derived from the different parts of the analysis are extended and discussed further. Table 9 in *Discussion and summed-up conclusions* finally summarises the ROI-values from the different cases. It should be clearly stated that since the initial investment is a very rough estimate, the calculations cannot be interpreted in the usual ROI manner. The ROI calculations should instead be considered as a way of differentiating the different scenarios.

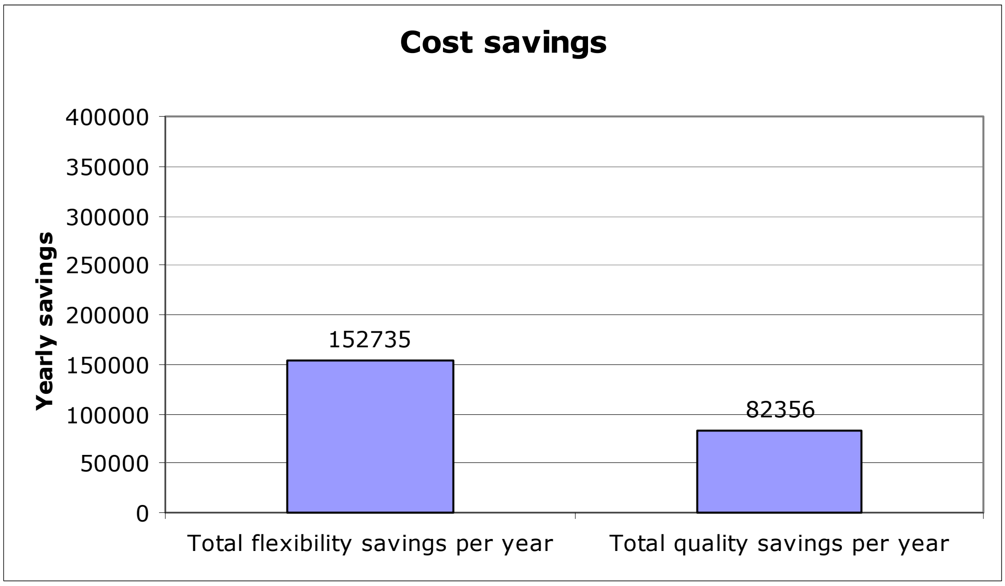
8.1.1 Basic calculations

The basic calculations are based on the information at hand displayed in Table 8 without any major assumptions added. Although repeated efforts have been conducted to obtain the information missing there are still gaps in the information needed in order to fully utilise the model. Therefore the basic calculations do not cover all the savings that might occur with DAS. Expenses might also increase that are overseen because of lack of information.

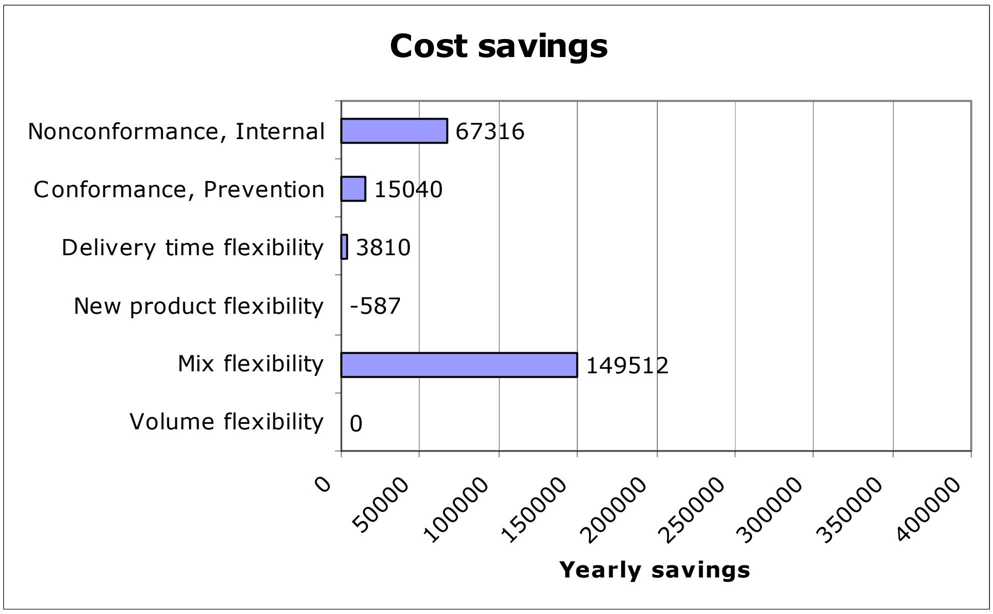
Regarding the basic case calculations on case company Z some assumptions have been added since information at hand is sparse. This calculation is therefore referred to as a combination of the basic calculations and the assumptions added.

8.1.1.1 Basic calculations - Case company Y

The ROI-calculation depends mostly on flexibility cost savings. According to Graph 2 the cost savings are mainly allocated to one major category, *Mix flexibility*. The reason for this is the labour cost savings from reduction of line managers originating from the merger of lines. Both *New product flexibility* and *Volume flexibility* are non-existent mainly because of information missing although it should be said that these categories might not be affected by an introduction of DAS. The basic calculations for case company Y leads to an ROI of 0.24.



Graph 1 Company Y Basic, savings divided into flexibility and quality

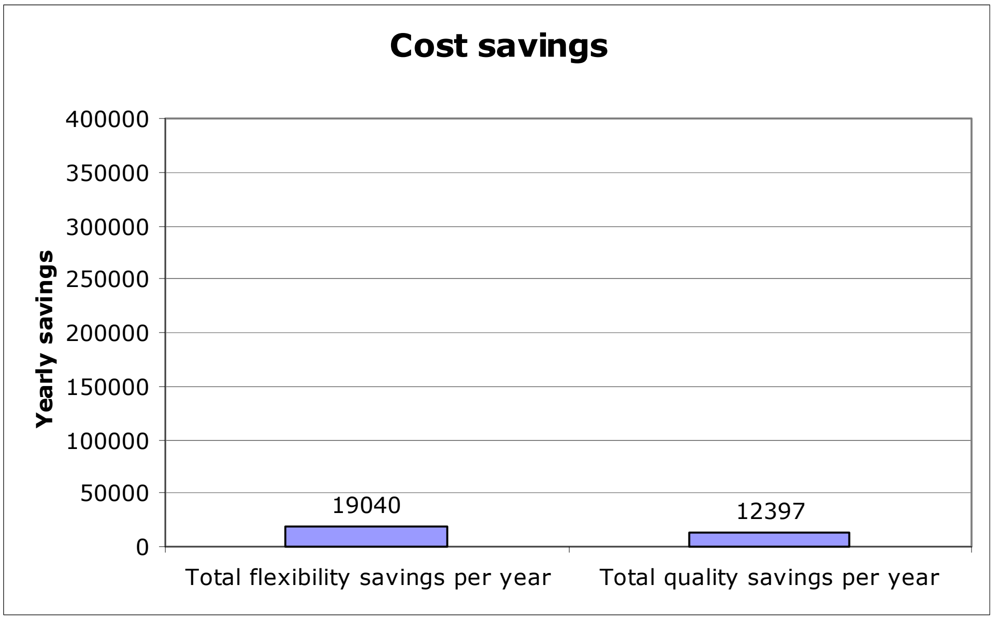


Graph 2 Company Y Basic, savings further divided into categories

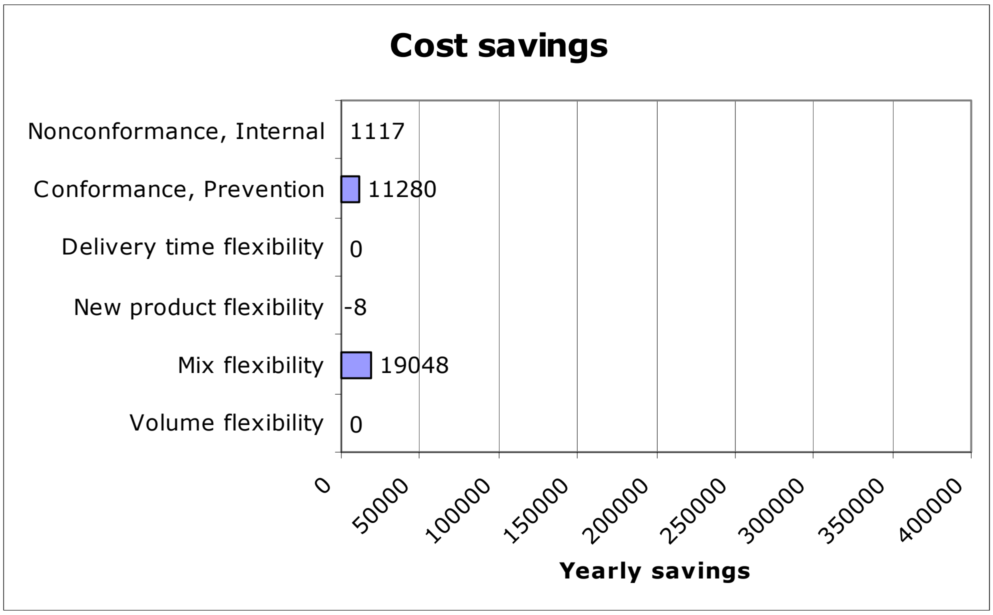
8.1.1.2 Basic calculations - Case company Z

The ROI reaches 0.04, forcing an investor to be both risk willing and patient to accept. One might however try to argue that some possibilities lie in the unexplored areas. Firstly a merger of lines at case company Z upon introducing DAS might raise the ROI to an acceptable level. Some operations are stated to be similar but not enough so to be performed by the same machine. This diminishes a merger to simply deal with a flow of different products reaching different machines. The conclusion is thereby that no valid arguments would tip the scale in favour of DAS proving it a sound investment at case company Z. In fact the calculation on the contrary proves an already rather obvious insight, namely that DAS is not suitable in certain industries. A DAS investment requires certain prerequisites in the production of the company as will be discussed in *Where DAS fits*. The production at case company Z is focused on reducing operation time and possibly change over times if the batch size reaches levels low enough. The improved control and thereby reduced repair rates and cassation rates also have little effect at case company Z since the total value invested in the parts is so low.

No further calculations will be done on case company Z since the improved basic calculations are quite clear and descriptive enough in it self.



Graph 3 Company Z Basic, savings divided into flexibility and quality



Graph 4 Company Z Basic, savings further divided into categories

8.1.2 Assumptions added

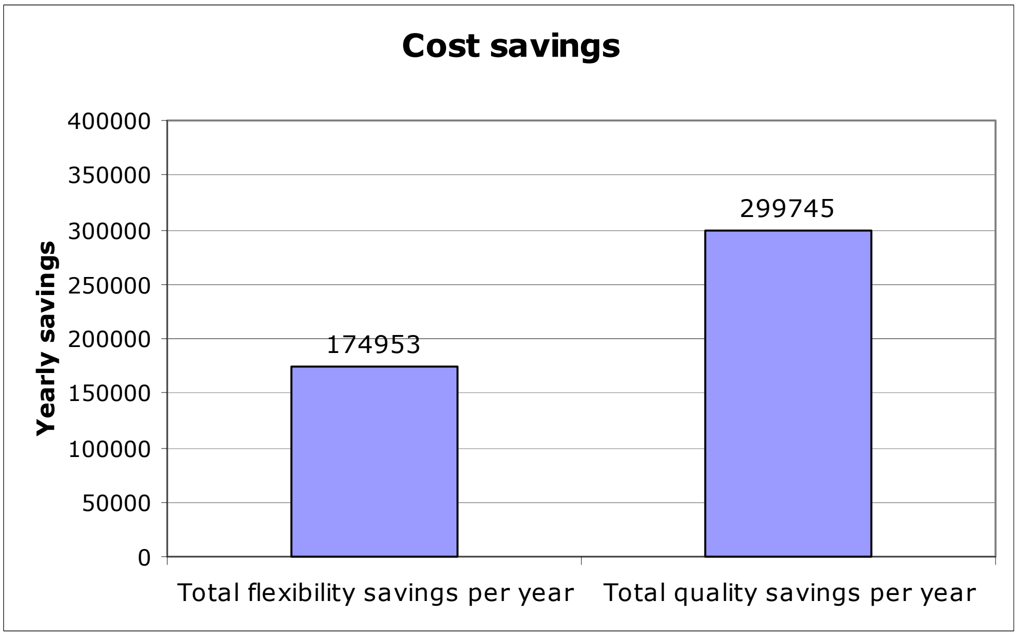
The numbers that have been assumed for case company Y in addition to the basic calculations are:

- The number of staff (**work centers**) that can be decreased is estimated to be 1, reaching 83 instead of 84. The reason for this is that the rate of failures is assumed to decrease leading to a higher plant capacity. To balance the PC for DAS with the present PC one less staff member is needed. This decrease leads to an allocation of 44 hours under **hours saved** in the delivery time flexibility category.
- The **operation time** has been cut down to 0.5. Upon review of the operation times they are deemed to be exaggerated, which is confirmed by company Y. This decrease affects both columns of data.
- The **rate of failures** is decreased by half reaching a level of 1 %. This assumption is based on the effects of the rerouting system and the increased control in the line and the assumption that a decrease in repairs leads to a decrease in failures.
- The change made to operating time also affects the **MLT**. Calculations on the MLT give a new value of 60 hours comprised of the operation time and the gluing, which decreases the **WIP**.
- The **interest rate** is set at 10 % since 6 % is not compatible in the business.
- It is assumed that case company Y invest in **quality systems** to the estimated amount of about 10000 S$ yearly. With a year comprised of 47 weeks the weekly cost incurred from quality system investments reaches an adjusted weekly level of 200 S$. The software included in the DAS software covers these kinds of investments and hence this cost zeros out.
- Due to the rather high rate of repairs and also failures it is assumed that **time spent on prevention** reaches a level of at least 10 hours a week. This kind of

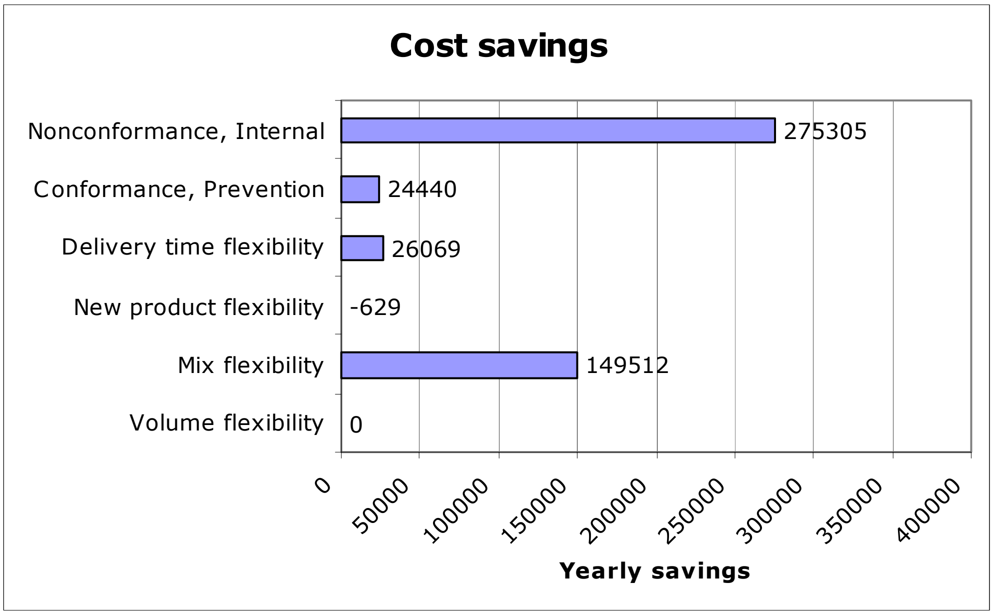
work is conducted by skilled staff earning 20 S$ an hour. Because of advantages with the control of process and the easiness to control the production flow through software the necessity of this preventive work is reduced to half, reaching a level of 5 hours weekly.

- According to observations **time spent on documentation** ought to exceed the 20 hours weekly stated in the basic calculations. Our assumption after observations is that 40 hours, corresponding to almost one full full-time employment, is spent on documenting the process.
- An additional effect of high rates on both repairs and failures is that time is spent on failure, trying to locate and identify the source of failure. This **time spent on failure** is approximated to be 10 hours weekly done by qualified staff. The time respectively for DAS is set to be half, 5 hours weekly.

After these assumptions being made, as displayed below, the major parts of the savings are due to quality related factors proving that there is much improvement to be made in that area. The savings incurred from a higher degree of flexibility are also substantial although not as high. The *New product flexibility* and *Volume flexibility* are still non-existent as was expected because of the completely manual operations in assembly. *Delivery time flexibility* is present as a cost saver but is very small compared to *Mix flexibility*. The ROI with the assumptions is 0.47.



Graph 5 Company Y Assumptions, divided into flexibility and quality



Graph 6 Company Y Assumptions, savings divided into categories

8.1.3 Scenario analysis

The assumptions used in this section will not be extensively explained since they are assumed to a high degree in similarity with a sensitivity analysis.

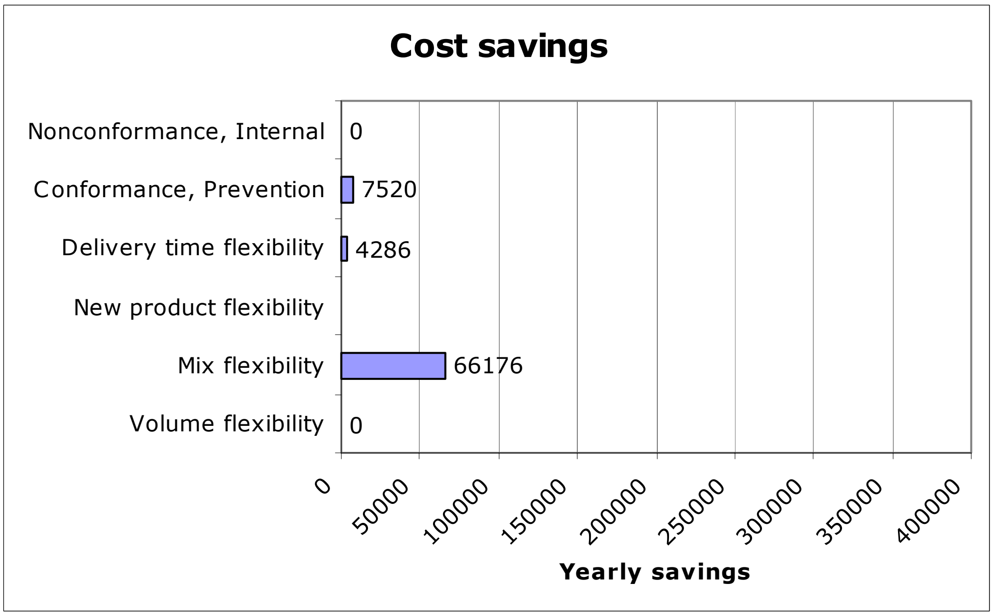
8.1.3.1 Company Y – worst-case scenario

The numbers that have been assumed / assessed are:

- The **time of production stop** is 0.5 hours which is the worst case scenario stated by FlexLink.
- Only one of the line managers can be made redundant reducing the number of **hours saved** to 44.
- The **floor space cleared** cannot be let to another party or be used for any other purpose.
- The **rate of repairs** is at 5 % and is unaffected.

Flexibility represents the significant part of the savings because the rate of failures in this case is left unaffected hence not impacting quality savings as in the basic case. This effect is evident in Graph 7 and also Graph 8. Some savings are to be made on *Mix flexibility* and *Conformance prevention. Delivery time flexibility* is represented but not more than just that. The ROI is no more than 0.08 calculating like this.

Graph 7 Company Y Worst-case, divided into flexibility and quality



Graph 8 Company Y Worst-case, savings divided into categories

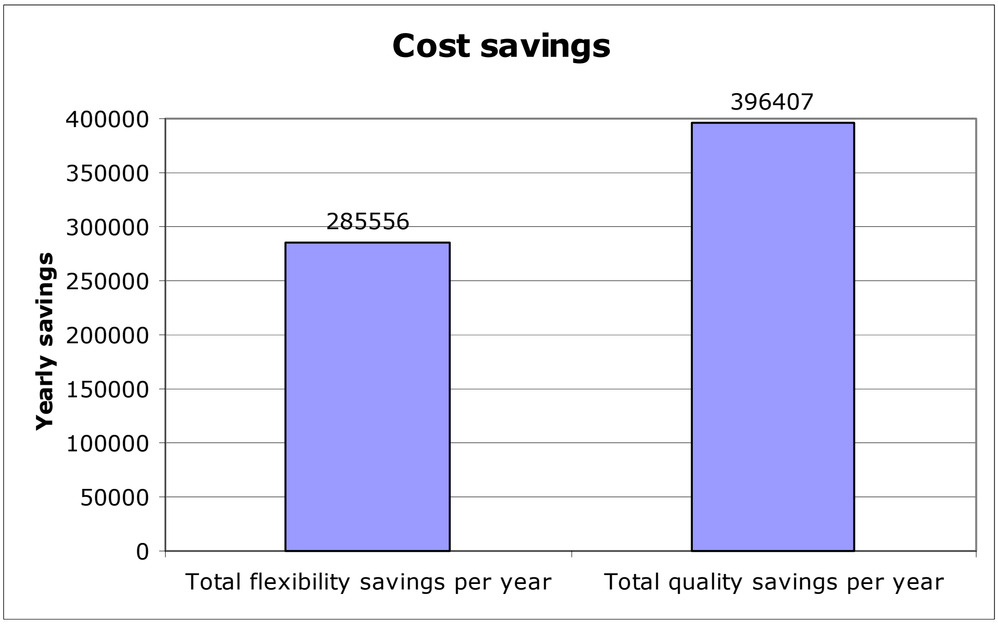
8.1.3.2 Company Y – best-case scenario

The numbers that have been assumed/assessed are:

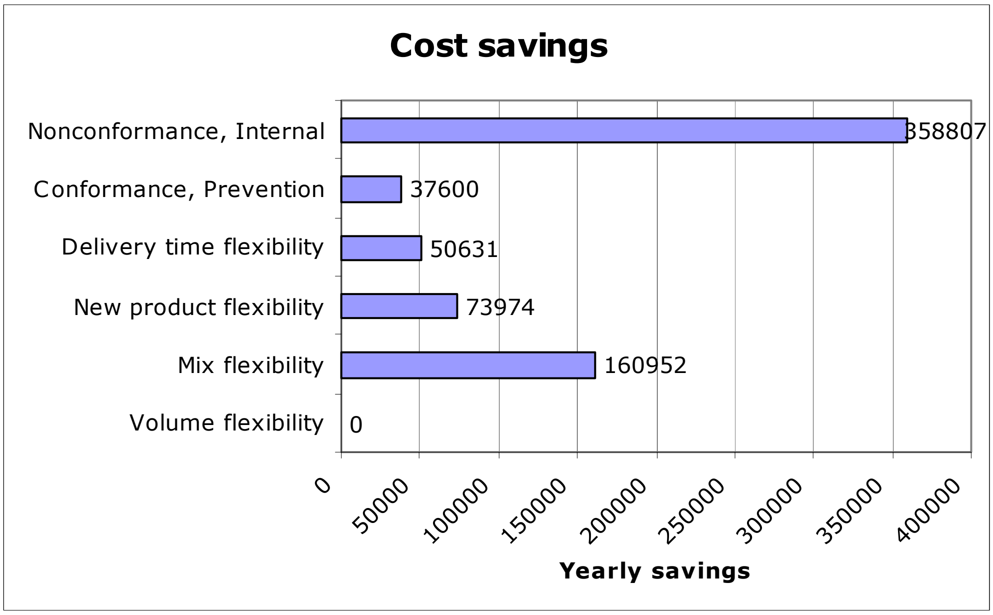
- Two of the floor staff members **(work centers)** can be made redundant maintaining the same plant capacity.

- The **operation time** is cut down to 0.45.
- The **rate of failures** is decreased to 0.5 % due to the rerouting system.
- The total **MLT** consisting of operation time and gluing is set to be 55 hours.
- The **interest rate** is set to 13 % since 6 % is not compatible with the business.
- The **time of production stop** is set at the best possible at 5 minutes equalling 0,0833 hours.
- The **floor space cleared** usually varies between 30-50 %. The space cleared in the basic calculations has therefore been increased by the factor of 5/3 giving the figure 166.67 sqm.
- The initial **ramp-up utilisation** is set to be 99 % compared to initially 97 % since it should decrease due to the possibility to simulate the ramp up before implementation.
- The **hours saved per week** under *Mix Flexibility* are 88 because of the two operators made redundant above.
- The **rate of repairs** is set as the worst-case scenario for the company at 10 % and the improvement rate of DAS is set at its maximum of 60 % giving a figure for DAS of 4 %.

The quality aspects are generating most of the savings even though the flexibility factors also generate substantial amounts. *Noncorformance internal* generates twice as much as *Mix flexibility* even though this is the largest of the flexibility factors. *Volume flexibility* is still stuck at zero. *Conformance prevention*, *Delivery time flexibility* and *New product flexibility* all gives rise to savings put together even if they are not large by themselves. The ROI, mind that it is not an ordinary ROI calculation, is at a staggering 0.68.



Graph 9 Company Y Best-case, divided into flexibility and quality



Graph 10 Company Y Best-case, divided into categories

8.1.4 Discussion and summed-up conclusions

Table 9 ROI-values from the different cases summarised

	Case company Y	Case company Z
Basic calculations	0.24	0.04
Assumptions added	0.47	-
Scenarios		
Worst case scenario	0.08	-
Best case scenario	0.68	-

8.1.5 Company Y

The basic calculations are not considered to be a correct description of reality even though this is based on the figures attained. This is due to problems related to the collection of the data. The problems comprise of both problems attaining figures and receiving contradictory ones. The section handling figures that included assumptions is the one most likely to occur. At the same time this section is of the least interest when evaluating the model since it does not highlight the importance of the different factors, and their impact on savings made with DAS. To evaluate the importance of different factors the scenario analysis is of great value. The variation between the worst- and best case scenario is as much as 0.6 which is to be expected when the assumptions are as coarse as those made. The importance of the rate of failures becomes evident upon reviewing the results. This is of course because of the high rate of failures at the company at hand but also that the product has a high value both in itself and in retail price. The different scenarios also show that the interest rate is of little value to the outcome. Hours saved and utilisation also have great effects on the outcome. It is worth paying attention to the effect of hours saved despite the low labour cost.

Due to the large variation between the worst- and best-case scenarios, and the difficulties with ROI it is hard to make any refuted conclusions about an investment in DAS at company Y. It is however possible to point out some advantages and disadvantages. According to the assumptions case no volume or new product savings could be attained. If company Y continue with manual manufacturing, the need for this kind of flexibility will not increase and the use of a DAS system in this aspect will not change. On the other hand, the system can contribute in the areas of quality and since this is very important for company Y, this suggests an investment in DAS. When evaluating a potential investment at company Y it is also important to consider the possibility to change the batch size. If the batch size is kept unchanged at 100 units the MLT will not decrease to any major extent with DAS. This is due to the fact that every unit has to “wait” for the other 99 in the batch to be handled before it can continue its way through the assembly. By changing the batch size to the tray size of 25 units, the MLT would shorten to less than 25 hours at the same time affecting WIP in a positive way. The possibility of doing this has however not been investigated.

In the authors’ opinion it can be concluded that an investment in DAS at company Y should be done.

8.1.6 Company Z

It has already been concluded that DAS according to our calculations is not a sound investment for case company Z almost independent of the initial investment. This is due to a number of reasons. Two important factors are that the plant is highly automated but still without benefits from merger of lines and the simple nature of the product diminishing the effects of a decrease in the rate of failures. That the batch size is 30,000 also highly influences the impact DAS would have. An additional contributing parameter is that there are very low cassation rates, considering the output, giving rise to very little costs since the unit cost also is very low. From the point of view that the research has been conducted it is hard to see how DAS could function as something more than simply a conveyor belt thus compromising the idea of the system. The fact that there are hardly any new product introductions and that machines more than twenty years old are still in use, since it can not be justified capacity wise to buy new ones, also pints out that the industry is mature, and has been so for quite some time, and it can thereby be concluded that the process is significantly developed. Taking all of this into account DAS is in the authors’ opinion not suitable for case company Z at this time. Two factors that possibly could have generated major savings, namely merger of lines and shortening of MLT, apparently did not hence supporting the notion that DAS is not suitable for the production at company Z.

8.2 Where DAS fits

8.2.1 Pattern matching DAS - Manufacturing system - FMS

When matching DAS to the different steps in a manufacturing process there are implications that DAS affects more than just the assembly. Testing and inspection are often included in the assembly line, which makes it possible to reroute defective parts in the line. DAS software controls the process and can be connected to other systems outside the assembly. Process control and decreased work in process will also have effects on the material handling and storage.

Since the definitions of what a flexible manufacturing system is, are almost equal to the number of users it is possible to state that DAS is a FMS. To be more specific DAS includes processing stations, material handling and a computer control system, which in general is distinguishing characteristics of FMS. The theories on FMS point out several benefits of FMS. Higher machine utilisation, reduced work-in progress, lower manufacturing lead times, greater flexibility in production scheduling, and higher labour productivity are benefits that can be proved when using FMS. These are also benefits that probably can be found after a DAS implementation. When talking about FMS the quality aspects are seldom mentioned. Computer control systems are a general basis in FMS, and it would be interesting to further investigate the general quality benefits of such systems.

The theories on the subject are unambiguous on the issue if FMS has to be applied to automated processes or not. As a part of the thesis we have investigated the possibility to apply DAS to two companies; one fully manual and one almost fully automatic. The case studies showed that the potential cost savings were higher for the company with manual processes than the one with automatic. Since the prerequisites for the two companies were totally different there are however little relevance of comparing the outcome and no refuted conclusions can in this case be made. When looking deeper at the outcome in the case with manual processes, no cost savings could be proved on the basis on volume and new product flexibility. The results are not surprising, because a manual system with wide skill is very flexible. The two categories of quality both gave rise to cost savings. The control and quality aspects of a process are maybe even more important in a manual process.

8.2.1.1 Need for flexibility

The theories stress that to survive and grow in the market, due to globalisation and rapid advances in process technology, the investments centred on a need for flexibility and quick response are important. Not to constraint these investments new investment metrics are needed. It is of course important that investments are not constrained because of for example insufficient methods of dealing with ROI. However to see flexibility and quick response as a universal solution seems to be somewhat of a simplification. Flexibility and quality are not the solution to all companies and as Buffa stresses FMS does not apply to all situations. This is also true when it comes to DAS. What situations are suitable for DAS? It is too easy to just say that DAS is adequate when the company needs quality control and flexibility. But how does one evaluate ones needs of quality and flexibility? Some writers discuss this problem and emphasize that it is important to match the manufacturing decisions to the manufacturing strategy and to the chosen market.

As the analysis of the case companies showed, some cost savings could not be verified. This can partly be explained by missing information and partly by the fact that there was no need for these categories of flexibility. At company Y no remarkable volume flexibility cost savings could be verified. At company Z no new product flexibility savings could be verified, as a result of the company introducing new products only about once every fifth year.

As mentioned before it is important to match the investment to the market. The manufacturing strategy surely derives from the market, but a deeper analysis of the current and future demands and requirements can be preferable when doing important investments. What happens to company Y if the labour cost increases dramatically? This is not an unreasonable thought since Singapore, like the other Asian countries, is in economic growth. With higher labour costs the price of being flexible in the way company Y is today would increase.

8.2.1.2 KSF applicable for DAS

It is not difficult to realise that more savings could be obtained if company Y needed more mix or if company Z needed to introduce more products. By using Porter's key success factors the need for flexibility and quality can be analysed. To evaluate the needs and advantages of DAS in every case, the KSF for the company must be matched to the prerequisites of DAS. It is therefore preferable to do the KSF analysis on the basis of the definitions of flexibility and quality.

DAS has some system characteristics that affect the analysis of where DAS is suitable. The pallet must be able to hold the products, and the weight limit of 30 kilos cannot be exceeded without adjustments. In other aspects there are no specific restrictions, even if the system can be more preferable in some cases than in others. There is no limitation on the number of products in the system, but a reason for sharing the system needs to be present. To only have one product in the system might not be cost efficient, due to loss of many of the flexibility aspects. In the same way batch size and output lack limitations as with the number of products. However if the batch size is very big the benefits of the system might not be applicable.

To start the KSF analysis the KSF questions of customer needs and the basis of competition will be considered. When answering these questions it is also important to analyse the environment the company is acting in. It is important to not only see to current demands and markets, but also to try to estimate the future demand and the trends in the industry. If the environment is stable, the future needs will be almost the same as the current, and the need for a new flexible system might not be apparent. The outcome of this KSF analysis will indicate what kind of flexibility and/or quality categories are important to the company.

8.2.1.3 KSF

Certain KSF correlate well with DAS and others subsequently do not. Factors that should be present upon an initial evaluation of the business in order to further investigate the possibilities of a DAS fit are stated below. They are derived from the calculations made but are not displayed in the same accordance. Not all of the factors listed will ever in truth be presented in one business but some should for it to be economically justified to invest in DAS.

Factors influenced by external power:

- The product life cycle is short.
- The market is dynamic and unpredictable.
- The demand is fluctuating.
- The delivery time is short.
- The product is custom made to a high extent.

- The product is of a high-technological nature.
- The product is valuable both in itself and in retail.
- There are demands on high degree of documentation and traceability.
- Quality is a qualifier not an order winner.
- The buyer sets the terms for the market.

These are often reflected internally by the following parameters:

- Many new product introductions.
- Batch production.
- Low batch sizes.
- High mix of products.
- Volume fluctuations.
- Platform production when possible.
- Much time spent on documentation and documentation handling.
- High rate of repairs and failures.
- Process control is important.

To consider in all cases are the effects of meeting or not meeting the market requirements. Interesting aspects are costs of handling changes with the existing systems, loss of revenue and potential increased revenue. By doing this analysis the understanding of the company's needs and potential effects on savings will increase.

Since several theories concerns the importance of flexibility to meet the new environment, it is reasonable to conclude that the benefits of DAS will increase in changing environments. If the technology development is fast and having the new technology can lead to advantages, it is more important to have a system that easily can be changed. Likewise, if the products have short life cycles the importance of reusability of the system and the ability to introduce new products will increase. The ability to meet the market requirements to a low cost can lead to a competitive advantage and increased revenue. Reversibly if the system restricts this ability the long-term survival of the company will be threatened.

DAS can be suitable in many different situations. To really see the potential with the system it is important to be aware about the KSFs at hand. An implementation of DAS can lead to cost savings, and many of the savings are associated with a quick market response.

8.3 Theoretical interpretation & development of the model

8.3.1 The basic assumptions of the model

The model is developed to evaluate savings incurred by an investment in DAS on the basis of potential cost savings in form of DAS being more flexible and sustaining a higher quality compared to the existing systems at the case companies. Previously in the analysis the outcomes of the study and the potential cost savings have been discussed. The question that will be answered in this part of the analysis is if the model fulfils its purpose. Is the model a usable tool to value flexibility and quality?

The theoretical interpretation and development is built on the basis of frequently used definitions of flexibility and quality. From these definitions measurable cost drivers are identified. The use of recognisable definitions will hopefully increase the usefulness of the model. All potential cost savings are then divided into one of the two categories flexibility savings and quality savings. The question is if all savings can be related to either flexibility or quality, if the right cost drivers have been identified and if the cost drivers' effects on cost are quantified in an adequate way?

It is not a certainty that all cost savings derived from an investment in DAS should be divided into either flexibility savings or quality savings. It can be argued that some savings are difficult to allocate to any of the two categories. On the other hand if a system is flexible and holds a high quality, is it then not reasonable to assume that all potential cost savings rest on the system's ability to be flexible and to hold a high quality? For example reduced work in process might not be directly related to flexibility. But reduced work in process depends on reduced non-value added time and shorter lead-time, which depend on the flexibility of the system.

One identified problem is the quality cost driver *documentation*. This cost driver includes all documentation in the assembly, even if all documentation is not connected to quality savings. The connection between for example automatic follow-up figures of the process and quality savings is not obvious. The model might be more accurate if documentation is divided into its different parts. The problem is that it can be difficult and time consuming to find data for all different types of documentation. Another problem is where to put documentation savings that do not fit into quality savings. A solution to this problem could be to add a category including general savings originating from the system.

To quantify the cost drivers' effect on cost structure manufacturing theories and formulas are combined and used. Since the model is suited to fit a manufacturing context, it is reasonable to believe that persons plausible to use the model are familiar with this kind of theories. By using well-known and accepted theories the simplicity and usefulness of the model should increase.

8.3.2 Trade-offs

Since the model is adapted to DAS, flexibility and quality is evaluated in the same model. It is important to consider if there is any cross impact between flexibility and quality that made this separation inadequate? Theories about trade-offs between flexibility and quality, emphasize that there is no common understanding on how flexibility and quality are interrelated. Some theories state that there is a correlation, while other theories state the inversely. Since this thesis is not focusing on the trade-offs between neither flexibility and quality nor between different types of flexibility and quality, no investigations have been done to verify or discard the theories about trade-offs. As an example it can be mentioned that flexibility in the shape of increased number of products in a line can lead to decreased quality. The explanation is that many different products in a line, will lead to more changeovers and more different factors to control. The importance of control over the individual products will therefore increase in order to keep the level of quality. DAS software is developed to handle the complexity of many different products, which suggest the use of flexibility and quality in the same model. Even if the definitions were treated separately when developing the model, it was sometimes hard to distinguish savings. This could indicate that some definitions are related or are prerequisites for one another. For example having many different products in the same system facilitates the ability to vary the volume. Some of the cost drivers are quantified using the same formula. Porter's theory on cost drivers' interaction also supports trade-offs between flexibility and quality and within the different types of flexibility.

8.3.3 Weaknesses of the model

When the model was applied to the case companies several weaknesses with the model was found. At the beginning the model did not consider the cost of not meeting the demand. Some cost drivers were also measured incorrectly. The model has been modified gradually to better fit reality, but weaknesses with the model still remains.

One weakness is that the model requires data that in some cases can be difficult to collect. The company might be unwilling to share sensitive information, like sales price. Other information, like non-value adding time and time spent on repairs, might be unknown to the company and must be collected through observations. Another reason why it might be difficult to get information is that an investment in DAS often involves organisational changes. Persons working in the assembly are directly affected by these changes, and are at the same time the most important persons to get information from about the assembly. Resistance to changes can lead to unwillingness to provide the information required.

Another problem is to get comparable figures regarding DAS. Since the model is investigating cost savings of a potential investment in DAS, the comparable data regarding DAS must be estimated. Estimating the initial investment cost is the most difficult, since this is dependent on the solution the customer chooses. The initial investment cost has a significant effect on the ROI calculations. Even if DAS data have been obtained through simulations, expert interviews, own knowledge and benchmarking, the accuracy about the data must be considered. The exact results of an implementation of DAS at the case companies cannot be known.

Even if data in some cases can be difficult to obtain, the model still offers an opportunity to analyse the situation. Persons with knowledge about the system at hand can try different sets of data and on the basis of the model compare the results from different scenarios.

8.3.4 Limitations of the model

Flexibility is complex partly because the word flexibility is widely used, and partly because flexibility does not define a state, but a potential to reach a new state. By using the most occurred definitions of flexibility the fragmentation of the definition of flexibility will not be enhanced. The model uses the definitions of volume, mix, new product and delivery time flexibility, all more or less definitions of changing states. A system can be called flexible when it is possible to change the state of the system to a low cost and in a short period of time. The two factors cost and time are often closely related. If a system cannot handle for example mix flexibility to a reasonable cost, this becomes a limitation of the system. The limitation leads to increased cost as a result of not being able to meet the demands of the market. If a system does not have volume flexibility, there is a cost of having over or under demand. A system that is more flexible can give rise to several cost savings, both when it comes to rebuilding the system and responding to the market. The model includes both the costs of rebuilding the system to a new state, and the cost of not being able to meet the new market requirements.

The impact of the new state and the new conditions are more difficult to measure. Important when introducing new products is the possibility to a quick market response. This could lead to increased market shares and increased revenue, which is not included in the model. The effects of a flexible system's ability to a quick market response can have great impacts on the company's revenue. The ability to quickly respond is however not only dependent on the manufacturing system. Other factors to consider are the organisation, the competition, the customers and the market.

The use of the four common definitions of flexibility and the two of quality is not entirely positive. By using the definitions there is a risk that the model leaves important factors out when evaluating flexibility and quality on the basis of DAS. For example the model does not take into account the fact that it is easy to make changes of DAS during the implementation phase. It is our impression that many of the authors on the subject discuss the potential of FMS but forget to address and understand the process of implementation. This process is time consuming and hence the prerequisites of the implementation are often changed during the process. Adjusting the design of the system to be implemented is then necessary and costly. A system that is easy to adjust to these changes minimises the costs derived from a change in prerequisites. This implementation flexibility is of course not always applicable but normally changes occur and quite often these tend to be very costly especially during the end of the implementation process.

When it comes to quality, the model only considers reaching a high quality as possible and not the possibility to alter the quality between products. Maybe this can be seen as a weakness, but there was no need to consider this fact when structuring the model. It is however still interesting and as companies produce a wider range of products within the same system, altering quality might become a cost and/or a competitive advantage.

Because of time constraints, the thesis is limited to consider only cost savings within the assembly line. This leaves out other parts of the value chain that are also affected by DAS such as order handling, design for assembly or kitting.

The external failure was neither taken into account since customer research would be needed. Also an implementation of DAS would not necessary incur a higher level of quality in the hand of the customer. However once external failures occur the reasons for these failures can be tracked and identified by investigating the logged production data. The increased knowledge about the problems in the process and the following countermeasures ought to increase the internal quality but still it is not possible to say whether or not the external failure rate is decreased.

8.3.5 Specific comments on certain areas of the model

It is rather unlikely that the demand should stay at the same level however this has been assumed due the difficulties to estimate it. It should also be noted that DAS might lead to a more sensitive system at case company Y regarding volume fluctuations since adding capacity might be slower, more time consuming, and more expensive.

Disregarding that batch sizes are different to different products is viable as long as a mean value is used and there are no extreme variations from this. If this is not the case this must be considered to be a frivolous assumption.

The main reason for the difficulty to compare the system at present with the DAS-concept is the authors' limited knowledge of the design and implementation of the system. Hence it has been hard to make assumptions and qualified guesses on what the effects of the DAS-concept would be.

The equations on over demand and under demand have not been applied to a large enough extent and have thereby not been verified. At case company Y they are not regarded since no under and over demand are supposed to exist. At case company Z where an under demand actually exist, this under demand is stated to depend on the machine usage, leading to the same capacity utilisation with the DAS-concept applied. The results from using the equation also shows that the effects of over and under demand impact the calculations greatly. Hence it can be concluded that these formulas, hard to apply, as well gives a misleading description of the actual situation. The equations need to be further developed and also the assessment of the demand situation ought to be dynamic instead of static as is the case now. The equation on *desirable over capacity* suffers from the same problem with an exaggerated impact on the calculations. DOC ought to generate a cost at case company Y because of overtime wages but this has not been addressed.

Appreciating the impact the introduction of new products has on production stop as well as ramp-up issues is tremendously difficult, hence, the uncertainty is large. A small change in the average time of production stop or the utilisation on ramp-up might lead to large effects especially if the number of new products per year is big.

The time spent on documentation is done by non-qualified workers in the line at case company Y. This is not strictly true since documentation is also performed by the line managers. The wages differ significantly and therefore the calculation of the savings on documentation might not be accurate but is done with caution. Hence the savings are not deemed to be exaggerated. Another aspect is that savings on labour are calculated on *Mix flexibility* from a reduced need of line managers. There is a risk that these savings and the savings on documentation would collide should the documentation done by line managers be taken into account as well. At the case company Z the documentation is done by qualified workers but there are no problems with colliding interests since there are no savings on labour from of merger of lines.

It is not likely that *plant capacity* and *production rate* would not change when introducing DAS. The reason for this is that no information on what changes would occur was acquired.

8.3.6 The authors' reflections on the model

Several writers discuss the difficulties of measuring flexibility. After developing our model, we agree with the writers and state that measuring flexibility and quality is not easy. With our model we present a way to measure flexibility and quality and even if the model still has some shortages, we think that we have contributed to the subject.

We would like to give some advice to future researchers on the subject by highlighting our own thoughts about the model and the development of it. A strength with our model is the break down of the definitions into cost drivers. This has made the otherwise complex definitions, easier to understand and measure. It also facilitated the development of formulas.

As mentioned above we had some problems collecting all required data. Some formulas require information that was not possible to get from our case companies. It should be preferable to consider the possibility to get required information when developing the formulas. A trade-off analysis between the level of the formulas, the results and the difficulties of collecting information should be done. Another way to evade the data problem could be to develop alternative formulas for each cost driver using different data.

Another thing to improve is to early on define what production is of interest for the system, and choose case companies based on these criteria. The outcome of our case studies showed that the system was not suitable for company Z. Since the production of company Z was not suitable for DAS, few categories of cost savings could be proved. This has affected the possibility to evaluate our model.

8.3.7 Generalisation of the model

The model is suited for a comparison between DAS and other systems. The cost drivers are identified regarding the possibilities of DAS. Since the model is adapted to a comparison to DAS, and only considers factors that differ with DAS, the general use of the model is limited.

DAS is a flexible manufacturing system, which could imply that the model can be used for other flexible manufacturing systems as well. The definitions of such a system is however too wide. To use the model to evaluate other systems, some modifications would be required. It is important to consider the system's similarity to DAS and what kind of savings the system gives rise to. The model only considers aspects of flexibility and quality that is affected by DAS.

On the other hand the model can be seen as a methodology in how to measure flexibility and quality in a manufacturing context. The model shows how to break down the definitions into measurable variables. All cost drivers except for merger of lines can be measured separately for each system. After measuring the cost drivers, a comparison between the systems are made and the difference calculated. These cost drivers can be used for a comparison between other systems as well. When it comes to the merger of lines the comparison is made directly and the difference with DAS is estimated and included in the cost driver formulas. By changing this cost driver, the general use of the model might increase. The model also constitutes guidance on what data is needed to evaluate flexibility and quality.

9 Conclusions

In this chapter final conclusions are made based on the previous chapters. This chapter aims at answering the questions asked in the problem discussion as well as fulfilling the purpose of the report.

The purpose of the thesis was to value flexibility and quality in a manufacturing context, applied to DAS, in order to use it in investment calculations. Several writers stress the difficulties of measuring flexibility. Some writers have given suggestions in how to measure flexibility but only a few have tried to actually do so. Due to the amount of literature on the subject and the fact that a lot of different people have opinions on the matter, we found it difficult to identify useful definitions of especially flexibility. Even though the literature on the subject is extensive not much material can be found linking definitions and quantifiables together. The theories also gave little support in how to measure flexibility and quality. The need for a specific model was evident and this thereby had to be developed by the authors. After developing our model and after conducting the case studies we agree with the other writers on the subject and state that measuring flexibility and quality is not easy. With our model we present a way to measure flexibility and quality and even if the model still has some shortages, we think that we have contributed to the subject.

The basis of the model is the most common definitions of flexibility and quality, namely; *Volume flexibility*, handling over- and under demand, *Mix flexibility*, handling the number of products in production, *New product flexibility*, handling the introduction of new products, *Delivery time flexibility*, handling delivery speed, *Prevention* handling time spent on prevention, and *Internal failure* handling repairs, failures and identifying reasons for failure. This proved to be a viable way of assessing flexibility and quality.

The easiest way to measure flexibility and quality is to subdivide it into cost drivers.

By applying the theoretical development and interpretation model at the case companies, cost savings of a conceptual DAS implementation could be evaluated. It becomes apparent upon reviewing the figures that DAS is, in our opinion, not suitable for company Z but on company Y. The reason for this is the specific prerequisites of the different plants.

When applying the model it became apparent that some required data was not possible to collect. The difficulty to attain unambiguous figures is a major problem. The results showed that in some of the eventualities certain categories have little or no effect on ROI. This effect the gathering of information across the board resulting in sometimes inadequate figures even concerning factors that would have been of interest. The consequence of this is that assumptions had to be made. The result thereby becomes questionable which is illustrated by the great span of ROI ranging from 0.8 to 0.68 at company Y. This can however be regarded as a positive treat of the model, since it can be used for calculating many different scenarios, but since time always is an issue focus on specific parts of the model is recommended.

When matching DAS to the different steps in a manufacturing process there are implications that DAS affect more than just the assembly. Simply considering assembly, when evaluating DAS is not enough since an implementation of such a system often affects both parts of the production as well as the organisation. A broader view is preferable if a complete survey of all savings made is required. DAS includes processing stations, material handling, and a computer control system, which in general is distinguishing characteristics of Flexible Manufacturing Systems. The literature discuss if FMS can be applied at manual processes. In our opinion is the issue of automatic or manual processes not of great importance, instead it is the prerequisites of the company's manufacturing that are of interest.

Some writers emphasize that flexibility is not a universal solution for all companies and that it is important to match the need for flexibility to the manufacturing strategy and to the market. How this match should be done is not however extensively discussed in the literature. The outcome of the case studies clearly showed that there was no need for the flexibility and quality savings that occurred from a conceptual thinking of DAS at company Z. A way of assessing specific companies' need for flexibility and quality, and what kinds of these are required, can be made by using Porter's Key Success Factors. To evaluate the needs and advantages of DAS in every case, the KSF for the company must be matched to the prerequisites of DAS. To consider when doing the KSF analysis are the effects of meeting or not meeting the market requirements. Interesting aspects are cost of doing changes with the existing systems, loss of revenue, and potential increased revenue. By doing the KSF analysis the understanding for the company's needs and potential effects on savings will increase. This is an easy way of determining early on if it is economically justifiable to invest in a system.

DAS can be suitable in many different situations. We have identified some important prerequisites for DAS displayed below. Not all of the factors listed will ever in truth be present in one business but some should be for it to be economically justified to invest in DAS.

Factors influenced by external power:

- The product life cycle is short.
- The market is dynamic and unpredictable.
- The demand is fluctuating.
- The delivery time is short.
- The product is custom made to a high extent.
- The product is of a high-technological nature.
- The product is valuable both in itself and in retail.
- There are demands on high degree of documentation and traceability.
- Quality is a qualifier not an order winner.
- The buyer sets the terms for the market.

These are often reflected internally by the following parameters:

- Many new product introductions.
- Batch production.
- Low batch sizes.
- High mix of products.

- Volume fluctuations.
- Platform production when possible.
- Much time spent on documentation and documentation handling.
- High rate of repairs and failures.
- Process control is important.

Through the case studies the theoretical development and interpretation model was tested. Since one of the case companies was not suited for DAS at all, and since only some cost savings could be proved at the other case company, it was not possible to thoroughly test the model. In order to evaluate the use of all the parts of the model more, or better suited, case companies would be necessary. At times certain factors are not present, or are deemed unimportant by the company, and all sections of the model have thereby not been implemented.

The difficulties when measuring flexibility and quality can partly be explained by the fact that flexibility and quality in many ways are not a "state" but rather a "change". The effects of a flexibility system's ability to a quick market response can have great impacts on the company's revenue, which is not included in the model. The ability to respond quickly is however not only dependent on the manufacturing system. Other factors to consider are the organisation, the competition, the customers and the rest of the market. By doing the KSF analysis, we believe that the possibility to increase the revenue can be evaluated further.

Since this thesis is not focusing on the trade-offs between neither flexibility and quality nor within different types of quality, no investigation have been done to verify the theories about trade-offs. After developing the model, it is however the authors' opinion that different definitions and cost drivers have an impact on each other. In the light of Porters theory about cost driver interaction, we could find support for interaction between flexibility and quality and between the different types of flexibility.

We have found the use of the common definitions of flexibility and quality not entirely satisfying. By using the definitions there is a risk that the model leaves important factors out when evaluating flexibility and quality on the basis of DAS. Another type of flexibility encountered that may be of importance when evaluating DAS is implementation flexibility that handles how flexible the system is when it comes to changes during implementation. This has however not been extensively investigated in this report.

The generalisation of the model is limited due to the model's adaptation to DAS. We believe however that the model can be seen as a methodology on how to measure flexibility and quality in a manufacturing context. The model shows how to break down the definitions into measurable variables. The model also constitutes guidance on what data are needed to evaluate flexibility and quality.

It is recommended to consider the possibility to get required information when developing the formulas. A trade off between the level of the formulas, the results and the difficulties of collecting information should be done. Even if data in some cases can be difficult to obtain, we believe that the model still offers a great opportunity to analyse the situation. Persons with knowledge about the system at hand can alter the data and on the basis of the model compare the results from different scenarios. The model can also provide great value as sales support.

10 Further research

Suggestions for further, complementing research is presented based mainly on the analysis and the conclusions and to some extent also on the preceding chapters.

Adaptation of the model to a general level. A model applicable to all kinds of FMS would be of interest in order to simplify the assessment of them and to compare benefits and drawbacks.

It would be interesting to use our model at other companies, and further evaluate our way of measuring flexibility and quality.

In the model, common definitions of flexibility and quality are used. A further investigation of the relationship between the definitions and cost drivers would be of great interest and could be the basis for further development of our model. Maybe the importance of the different definitions and cost drivers can be ranked.

Evaluation of DAS after an implementation to evaluate the actual benefits and cost savings made.

Evaluation of whether or not having better process control directly correlates with other parts of the value chain.

Further investigation of the quality aspects of FMS. When FMS is discussed the quality aspects are seldom mentioned. Computer control over the process is a general basis in FMS, and it would be interesting to further investigate the general quality benefits of such systems. For example it is reasonable to argue that if quality in the shape of prevention is improved it should have external quality effects as well. The feasible connection between prevention and external failure would thereby be of interest to investigate.

Flexibility and quality is not the solution for all companies. The use of KSF is one way of evaluating the need of the two factors. A further investigation on how this KSF analysis should be done would be of great interest.

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Appendix 1 – Cost drivers

The following table lists all measurables affecting a certain formula, cost driver or calculation. Hence it is possible to identify which measurables are needed to fully be able to use certain formulas. The underlined variables in the column on measurables needed refer to certain formulas in the table. For example *production rate* is needed to calculate *plant capacity* leading to the necessity to identify the measurables needed to calculate *production rate* if *plant capacity* is to be addressed.

Table 10 The measurables and their connection to the different categories.

Formula	**Measurables needed**
Plant capacity	Number of work centers, shifts per week, hours per shift, production rate
Utilization	Output, plant capacity
Production rate	Set up time, quantity of the batch, operation time, number of failures
Total cost invested in part	Alternative 1 Total cost according to case company Alternative 2 Material cost, costs for set up time and operation time, cost for non operation time
WIP	Plant capacity, utilization, shifts per week, hours per shift, MLT
MLT	Set up time, quantity of the batch, operation time, non operation time
ROI	Profit (total cost saving), initial investment for DAS

Category	Cost driver	Calculations required	Measurables needed
FLEXIBILITY			
Volume flexibility	Under demand Over demand	Cost of under demand Cost of over demand	Total cost invested in part, material cost, plant capacity, time of under demand, units requested by the market, desirable over capacity, percentage of capacity transferred for another use Average extra cost of production exceeding PC, units requested by the market, plant

	Capacity change	Cost of production stop	capacity, time of over demand Total cost invested in part, material cost, production rate, time and cost of production stop, cost of planning, overtime, increased overhead, cost of incremental investment
Mix flexibility	Merger of several lines Change over time	Machine cost Labour cost Floor space Total cost of change over Approximation formula	Capital cost associated to machine, AOHC machine Wage paid to staff member, AOHC staff member, hours saved Floor space cleared, cost of floor space per area Cost of single change over, number of changeovers Percentage of total output for product *i*
New product flexibility	General Capacity adjustment Ramp-up	Total cost of introducing new products Cost of production stop Incremental investment Cost of ramp-up utilization	Cost on average for a new product introduction, number of new product introductions *Same as above* - capacity change! Cost of incremental investment, Utilization during ramp-up, time of ramp-up, number of parts produced, total cost invested in a part, material cost, cost for planning, overtime and increased overhead, number of ramp-ups
Delivery time	Reduced non-value	Cost for WIP	WIP, Total cost

flexibility	time Loss of revenue	 Labour cost Cost of over demand	invested in part, material cost, interest rate Wage paid to staff member, AOHC staff member, hours saved Number of less sold products, cost of a single less sold product
QUALITY			
Conformance - Prevention	Quality system Time spent on prevention Documentation	 Cost of time spent on prevention Cost of documentation	Cost of quality systems Time spent on prevention, wage paid to staff member, AOHC staff member Time spent on documentation, wage paid to staff member, AOHC staff member
Non-conformance - Internal	Repairs Failures Time spent on failure	Cost of repairs Cost of failures Cost of time spent on failure	Time spent on repairing one unit, wage paid to staff member, AOHC staff member, cost of material, rate of repairs, number of parts made Total cost invested in a part, time spent in production MLT, units taken out of production, number of parts produced, Time spent on failure, wage paid to staff member, AOHC staff member

Appendix 2 – Calculations

The calculations are based on the Eq. [1] to Eq. [25] with some additional changes added. When the calculations are left out it is because the certain figure has been attained directly from the company or calculated or estimated as presented in the text. Also some calculations are left out since they result in zero cost savings.

The results indicated in bold and at the same time are underlined refer to weekly cost savings and these are summarised leading to the total cost saving. This is then multiplied with the number of weeks per year being 47.

Some of the calculations include compensation for the number of active weeks differing from the normal 52. The calculations to the left refer to the system as configured now whereas the calculations to the right regard the impact of the DAS-concept. When it has not been possible to put the calculations side by side because of lack of space the first calculation refer to the present system followed by the DAS-concept.

Any differences between these calculations and the figures presented in the text are a result of the figures being rounded off.

Calculations on the basic case at case company Y

[1] $$MLT = \sum_{i=1}^{n} (T_{SUi} + Q \cdot T_{Oi} + T_{NOi})$$

$MLT = 72$ $\qquad$ $MLT = 64$

[2] $$\frac{batchtime}{machine} = T_{SU} + \frac{Q \cdot T_O}{(1-q)}$$

For calculation see Eq. 3 $\qquad$ For calculation see Eq. 3

[3] $$Rp = \left(\frac{Q}{T_{SU} + \frac{Q \cdot T_O}{(1-q)}} \right)$$

$$Rp = \left(\frac{100}{0.33 + \frac{100 \cdot 0.53}{(1-0.02)}} \right) = 1.84$$

$$Rp = \left(\frac{100}{0.083 + \frac{100 \cdot 0.53}{(1-0.02)}} \right) = 1.85$$

[4] $$PC = W \cdot S_W \cdot H \cdot Rp =$$

$$PC = 84 \cdot 5 \cdot 8.8 \cdot 1.84 = 6793$$

$$PC = 84 \cdot 5 \cdot 8.8 \cdot 1.85 = 6824$$

[5] $U = \frac{output}{PC}$

$U = \frac{8500}{6793}$ = 125 % $U = \frac{8500}{6824}$ = 125 %

[6] $WIP = \frac{PC \cdot U}{S_W \cdot H}(MLT)$

$WIP = \frac{6793 \cdot 1.25}{5 \cdot 8.8}(72)$ = 13909 $WIP = \frac{6824 \cdot 1.25}{5 \cdot 8.8}(64)$ =
= 12364

[7] $C_{PC} = C_M + \sum_{i=1}^{n}(C_O \cdot T_{Pi} + C_{NOi})$

$C_{PC} = 50.18$ $C_{PC} = 50.18$

[8] $ROI = \frac{profit}{investment}$

$ROI = \frac{235047}{1000000}$ = 0.24

Volume flexibility

[9]

$C_{UD} = (PC(1 - DOC) - demand)(1 - OC_T)\delta(\mathrm{C_{PC}} - \mathrm{C_M})\mathrm{T_{UD}} + C_{UDP}$

$C_{UD} = 0$ $C_{UD} = 0$

[10] $C_{DOC} = DOC \cdot PC(C_{PC} - C_M)$

$C_{DOC} = 0$ $C_{DOC} = 0$

[11] $C_{OD} = \tau \cdot \varepsilon(demand - PC) \cdot T_{OD}$

$C_{OD} = 0$ $C_{OD} = 0$

[12] $C_{CE} = C_{PS} + C_I$

$C_{CE} = 0$ $C_{CE} = 0$

[13] $C_{PS} = (C_{PC} - C_M) \cdot R_p \cdot T_{PS} + C_{PSP}$

$C_{PS} = 0$ $C_{PS} = 0$

Volume = 0 (0)

Mix flexibility

[14] $C_{MM} = 0$ $C_{MM} = 0$

[15] $C_{FS} = FS \cdot C_{FSSM}$ $C_{FS} = 100 \cdot 3.3 \cdot \frac{52}{47} =$
= 365 (17155)

[16] $C_L = \sum_{i=1}^{n} T_{Li} \cdot W_{Li} \cdot (AOHC_{Li} + 1)$

$C_L = 88 \cdot 20 \cdot (0.6 + 1) =$
= **2816**

[17] $C_{CO} = C_{SCO} \cdot N_{CO}$
$C_{CO} = 0$ $C_{CO} = 0$

[18] $N_{CO} = (1 - \sum_{i=1}^{n} x_i^2) \frac{output}{batchsize}$
Equation not used. Equation not used.

Mix = 3181 (149507)

New product flexibility

[19] $C_{NP} = C_{ANP} \cdot N_{NP}$
$C_{NP} = 0$ $C_{NP} = 0$

[13] $C_{PS} = (C_{PC} - C_M) \cdot R_p \cdot T_{PS} + C_{PSP}$
The production stops due to the introduction of new products is calculated using Eq. [13] multiplied with the average number of new products per week, hence the 1.28 figure in the calculation below.
$C_{PS} = 0$
$C_{PS} = \left((50.18 - 32) \cdot 1.85 \cdot 0.3 + 0\right) \cdot 1.28$ = 13
0 – 13 = **13 (-611)**

[20] $C_{RU} = ((1 - U_{RU}) \cdot T_{RU} \cdot output \cdot (C_{PC} - C_M) + C_{PRU}) \cdot N_{RU}$
$C_{RU} = 0$ $C_{RU} = 0$

New product = -12 (-611)

Delivery time flexibility

[21] $$C_P = \sum_{i=1}^{n} T_{Pi} \cdot W_{Li} \cdot (AOHC_{Li} + 1)$$

$$C_P = 0$$

[..] The following equation can not be found in the text. The cost of the product to multiply with the WIP and the interest rate is calculated as the average cost of the products within the system.

$$C_{WIP} = WIP \cdot \left(\frac{(C_{PC} - C_M)}{2} + C_M \right) \cdot i$$

$$C_{WIP} = 13909 \cdot \left(\frac{(50.18 - 32)}{2} + 32 \right) \cdot 0.06 \cdot \frac{1}{47}$$ = 730

$$C_{WIP} = 12364 \cdot \left(\frac{(50.18 - 32)}{2} + 32 \right) \cdot 0.06 \cdot \frac{1}{47}$$ = 649

730 – 649 = **81 (3807)**

Delivery time = 81 (3807)

Conformance prevention

[22] $$C_D = \sum_{i=1}^{n} T_{Di} \cdot W_{Li} \cdot (AOHC_{Li} + 1)$$

$$C_D = 20 \cdot 20 \cdot (0.6 + 1)$$ = 320

$$C_D = 0$$

320 – 0 = **320 (15040)**

Conformance =
= 320 (15040)

Nonconformance internal

[23] $$C_R = (H \cdot W_R \cdot (AOHC_R + 1) + C_{RM}) \cdot r \cdot output$$

$$C_R = (0.625 \cdot 5 \cdot (0.6 + 1) + 0) \cdot 0.075 \cdot 8500$$ = 3188

$$C_R = (0.625 \cdot 5 \cdot (0.6 + 1) + 0) \cdot 0.0413 \cdot 8500$$ = 1755

3188 – 1755 =
= **1432 (67304)**

[24.1] $$C_{FAIL} = \sum_{i=1}^{n} (C_{PC\,i} \cdot \frac{T_{Ci}}{MLT}) \cdot q_i \cdot output$$

Equation not used.

Equation not used.

[24.2] $$C_{FAIL} = C_{PC} \cdot q \cdot output$$

$$C_{FAIL} = 50.18 \cdot 0.02 \cdot 8500$$ = 8531

$C_{FAIL} = 50.18 \cdot 0.02 \cdot 8500$
= 8531
8531 – 8531 = 0

[25] $$C_F = \sum_{i=1}^{n} T_{Fi} \cdot W_{Li} \cdot (AOHC_{Li} + 1)$$

$C_F = 0$ $C_F = 0$

Nonconformance =
= 1432 (67304)

Weekly savings summarised = 0 + 3181 **-** 13 + 81 +320 +1432 = **<u>5003</u>**
Yearly savings = 0 + 149507 **-** 611 + 3807 + 15040 + 67304 = **<u>235047</u>**

Calculations on the basic case at case company Z

[1] $MLT = 72$ $MLT = 72$

[2] For calculation see Eq. 3 For calculation see Eq. 3

[3] $Rp = \left(\dfrac{30000}{12 + \frac{30000 \cdot 0.015}{(1-0.008)}} \right)$ = 64.43 $Rp = \left(\dfrac{30000}{12 + \frac{30000 \cdot 0.015}{(1-0.008)}} \right)$ =

= 64.43

[4] $PC = W \cdot S_W \cdot H \cdot Rp =$

$PC = 4 \cdot 10 \cdot 8.63 \cdot 64.43 =$ 22241

$PC = 4 \cdot 10 \cdot 8.63 \cdot 64.43 =$ 22241

[5] $U = \dfrac{16000}{22241}$ = 72 % $U = \dfrac{16000}{22241}$ = 72 %

[6] $WIP = \dfrac{22241 \cdot 0.72}{10 \cdot 8.63}(72)$ = 13349 $WIP = \dfrac{22241 \cdot 0.72}{10 \cdot 8.63}(72)$

= 13349

[7] $C_{PC} = 3.5$ $C_{PC} = 3.5$

[8] $ROI = \dfrac{31443}{800000}$ = 0.04

Volume flexibility

[9] Results in the same figures with the present system as with the DAS-concept. This is commented in the analysis of the model.

[10] Results in the same figures with the present system as with the DAS-concept.This is commented in the analysis of the model.

[11] $C_{OD} = 0$ $C_{OD} = 0$

[12] $C_{CE} = 0$ $C_{CE} = 0$

[13] $C_{PS} = 0$ $C_{PS} = 0$

Volume = 0 (0)

Mix flexibility

[14] $C_{MM} = 0$ | $C_{MM} = 0$

[15] | $C_{FS} = 111 \cdot 3.3 \cdot \frac{52}{47} =$
= 405 (19035)

[16] | $C_L = 0$

[17] $C_{CO} = 150 \cdot 0.625 = 93.8$ | $C_{CO} = 150 \cdot 0.625 = 93.8$
93.8 – 93.6 = 0

[18] Equation not used. | Equation not used.

<u>Mix = 405 (19035)</u>

New product flexibility

As stated in the text this category of flexibility is not addressed.

New product = 0 (0)

Delivery time flexibility

[21] | $C_P = 0$

[..] $C_{WIP} = 13349 \cdot \left(\frac{(2.3 - 0.06)}{2} + 0.06 \right) \cdot 0.10 \cdot \frac{1}{47} = 34$

$C_{WIP} = 13349 \cdot \left(\frac{(2.3 - 0.06)}{2} + 0.06 \right) \cdot 0.10 \cdot \frac{1}{47} = 34$

34 – 34 = 0 (0)

Delivery time = 0 (0)

Conformance prevention

[22] $C_D = 20 \cdot 12 \cdot (0 + 1) = 240$ | $C_D = 0$
240 – 0 = **<u>240 (11280)</u>**

Conformance =
= 240 (11280)

Nonconformance internal

[23] $C_R = (0.1 \cdot 6 \cdot (0 + 1) + 0.06) \cdot 0.005 \cdot 16000 = 53$

$C_R = (0.1 \cdot 6 \cdot (0+1) + 0.06) \cdot 0.00275 \cdot 16000$ = 29

53 – 29 = **<u>24 (1128)</u>**

[24.1] Equation not used. Equation not used.

[24.2] $C_{FAIL} = 2.3 \cdot 0.008 \cdot 16000$ = 294

$C_{FAIL} = 2.3 \cdot 0.008 \cdot 16000$ = 294

294 – 294 = 0

[25] $C_F = 0$ $C_F = 0$

Nonconformance =
= 24 (1128)

Weekly savings summarised = 0 + 405 + 0 + 0 +240 +24 = **<u>669</u>**
Yearly savings = 0 + 19035 + 0 + 0 + 11280 + 1128 = **<u>31443</u>**

Calculations on Y with assumptions added

These calculations are based on the basic case and hence only the parts of the calculations that are new from this will be presented. This means that changes in operation time, MLT and so forth will not be presented whereas calculations not explained before will be addressed.

Quality system

No calculation needed since figure is given on a weekly basis and this cost is zeroed out with the DAS-concept leading to a saving that equals the prior cost.

Time spent on prevention

[21] $$C_{PR} = \sum_{i=1}^{n} T_{PRi} \cdot W_{Li} \cdot (AOHC_{Li} + 1)$$

$C_{PR} = 10 \cdot 20 \cdot (0.6 + 1) = 320$

$C_{PR} = 5 \cdot 20 \cdot (0.6 + 1) =$
= 160
320 – 160 = **160 (7520)**

Time spent on failure

[25] $$C_{F} = \sum_{i=1}^{n} T_{Fi} \cdot W_{Li} \cdot (AOHC_{Li} + 1)$$

$C_{F} = 10 \cdot 20 \cdot (0.6 + 1) = 320$

$C_{F} = 5 \cdot 20 \cdot (0.6 + 1) =$
= 160
320 – 160 = **160 (7520)**

Calculations on best and worst-case at case company Y

These calculations are based on the case with the assumptions added and hence only the parts of the calculations that are new from this will be presented. The only type of calculation not used before is the calculation of ramp-up effects.

[20]
$$C_{RU} = ((1 - U_{RU}) \cdot T_{RU} \cdot output \cdot (C_{PC} - C_M) + C_{PRU}) \cdot N_{RU}$$

$$C_{RU} = ((1 - 0.97) \cdot \frac{528}{5 \cdot 8.8} \cdot 8500 \cdot (50.18 - 32) + 0) \cdot 0.043 = 2367$$

$$C_{RU} = ((1 - 0.99) \cdot \frac{528}{5 \cdot 8.8} \cdot 8500 \cdot (50.18 - 32) + 0) \cdot 0.043 = 789$$

2367 – 789 =
= **1578 (74166)**

Appendix 3 – Crib of denotations used in the formulas

Table 11 Complete list of variables including denotation, explanation and units

Denotation	Explanation	Units[170]
δ	1 if ((1-DOC)PC – demand)(1-C_T)≥0, else δ = 0	
τ	1 if (demand – PC)>0, else τ = 0	
ε	average extra cost of production exceeding PC, subcontract production or lost sales depending on strategy	S$/unit
$AOHC_L$	allocated overhead cost associated to staff member	percentage of W_L
$AOHC_M$	allocated overhead cost associated to machine	percentage of C_{CM}
batchtime/ machine	total batch time for given machine	hours
C_{ANP}	cost on average for a new product introduction	S$
C_{CE}	cost of capacity expansion	S$
C_{CM}	capital cost associated to machine	S$
C_{CO}	total cost of change over	S$
C_D	cost of time spent on documentation	S$
C_{DOC}	cost of desirable over capacity	S$
C_F	cost of time spent on failure	S$
C_{FAIL}	cost of failures	S$
C_{FS}	cost of floor space cleared	S$
C_{FSSM}	cost of floor space per area	S$/ m^2
C_I	cost of incremental investment	S$
C_L	cost of saved labour	S$
C_{LD}	cost of a single less sold product associated to the extent of delivery time	S$
C_{LMLT}	cost of saved labour associated to shorter MLT	S$
C_M	material cost	S$/unit
C_{MM}	cost associated with machines when merging lines	S$
C_{NO}	nonoperation costs	S$
C_{NP}	total cost of new product introduction	S$
C_O	cost for set up times and operation times	S$
C_{OD}	cost of over demand	S$
C_{PC}	total cost invested in part	S$/unit
C_{PR}	cost of time spent on prevention	S$
C_{PRU}	cost of planning, overtime and increased overhead associated to ramp-up situations	S$
C_{PS}	cost of production stop	S$
C_{PSP}	cost of planning, overtime and increased	S$

[170] If not otherwise specifically stated the units are based on weekly calculations.

	overhead associated to production stop situations	
CQS	cost of quality system	S$
C_R	cost of repairs	S$
C_{RM}	cost of material scrapped	S$
C_{RU}	cost of ramp-up utilisation	S$
C_{SCO}	cost of single change over	S$
C_{UD}	cost of under demand	S$
C_{UDP}	cost of planning associated to under demand situations	S$
demand	units requested by the market	units
DOC	desirable over capacity	percentage of PC
FS	floor space cleared	m^2
H	hours per shift	hours
i	interest rate	
MLT	manufacturing lead time	hours
N_{CO}	number of changeovers	number/week
N_{LD}	number of less sold products associated to the extent of delivery time	units/week
N_{NP}	number of new product introductions	number/week
N_{RU}	number of ramp-ups	number/week
OC_T	percentage of over capacity transferred for another use	
output	number of parts actually produced	units/week
PC	plant capacity	units/week
Q	quantity of the batch	units
q	units taken out of production	units
r	rate of repairs	percentage of output
R_P	production rate	units/hour
S_W	shifts per week	number/week
T_D	time spent on documentation	hours
T_F	time spent on failure	hours
T_L	hours saved	hours/week
T_{LMLT}	hours saved associated to shorter MLT	hours/week
T_{NO}	nonoperation time spent at the machine or workstation	hours
T_O	operation time	hours
T_{OD}	time of over demand	weeks
T_P	average production time per unit of product for given machine	hours
T_{PR}	time spent on prevention	hours
T_{PS}	time of production stop	hours
T_R	time spent on repairing one unit	hours
T_{RU}	time of ramp-up	weeks
T_{SU}	set up time	hours
T_{UD}	time of under demand	weeks
U	utilisation	percentage
U_{RU}	utilisation during ramp-up	percentage of

		output
W	number of work centers	number/week
WIP	work in process	units
W_L	wage paid to staff member	S$
X	percentage of total output for product	percentage of output

Appendix 4 – Interview Guide

The interview guide shows the questions asked to the case companies during the explanatory and exploratory case studies.

Questions to case company Y and case company Z

Why the information is needed

The questions were asked for different purposes. A mapping of the current assembly process was made to get a starting point for the study and a general picture of the company. The potential of the DAS concept was also compared to the current manufacturing process at the case company. To form an image about the investment decisions information was needed concerning calculation methods, and interest rates used. Questions to evaluate the means of flexibility and quality in a manufacturing context were also asked. To quantify the quality benefits information about repairs, failures and documentation was needed.

Information needed

The questions below have been asked to the case companies Y and Z. Some modifications of the questions have sometimes been done to fit the company at hand.

Factory/assembly
How is the factory layout? Storage locations?
Requirements, needs, problems?
What is your total plant capacity?
What is your utilisation rate calculated by this?
Overall flowchart, different work phases, and detailed work descriptions?
How many steps are there in assembly?
What are the different steps in assembly?
Are there any operations that are the same in the different lines?
How many work centres do you have?
How many shifts per week are there?
How many hours per shift are there?
What is the capital cost for each machine?
What are the AOHC costs for the same?
What are the wages for all parties included?
What are the AOHC for the same?
What is the cost for floor space?

Production mapping
How many different products are produced?
How many variations are there in total?
What is the mix (percentage), between these, and are there any daily/weekly variations?
How many products can be manufactured simultaneously?
Cycle times for each operation in the assembly line?
What are the box/tray sizes and the amount of products in each?
What is the set up time?

What is the cost associated with this?
What is the operation time?
What is the cost associated with this?
What is your non-operation time?
What is your cost associated with this?
What is the material cost?
What is your manufacturing lead-time?
What is the change over time between the different products?
How many change-overs do you have per week?
What is the cost of a change over?
Tools needed and equipments in different operations, sizes of equipments?
Are any of the products and components tracked during production and what products/components are desirable to track?

Documentation
Total number of employees working with documentation?
How is documentation created and by whom?
What kind of information is documented?
In what manner is the information stored?
Who uses the information and for what purpose?
How is the documentation system controlled and managed?
How much time is spent on creating and maintaining documentation?
What are the six production planners doing exactly?
How does the order handling and manufacturing execution in BAAN work today?

Products
What is the average batch size?
What is the average selling price?
What is the manufacturing cost on the different products?
What is the total cost invested in one unit?

Cost of new products
How often is a new product, or variation on an existing one, introduced?
What are the costs of introducing a new product, or a new variant of an existing product, today?
How long is your ramp up time for new products?
What is your utilisation during this time?

Failures and repairs
What is the ratio of failures/repairs?
Of the products that are sent to repair, what percentage has to be scrapped?
Is this number consistent or does it fluctuate, and if so what are the factors influencing this?
How are these documented, are there any changes being made due to this?
How much time is spent on repairs?
What products have the most failures?
Is quality checked only in the final stage before packaging?

At each specific testing station

How many test stations are placed in the production process and where are they placed?
How much is the total cost invested in the part so far?
How many hours have the products spent in the line prior to it?
What is the material cost for scrapping at that station?
What is the number of failures at this station?
What is the number of repairs?
How much time is spent on repairs?
What is the wages paid to the people working with repairs?
What is the AOHC to the same?
What is the cost of material scrapped when repairing?
What are the wages to the people handling the part so far?

Way to calculate investments
What aspects do you consider when deciding upon making new investments?
What way of calculation is used when deciding upon making a new investment?

Other production aspects
How do you measure productivity and what are your goals?
Where are you today in relation to these goals?
What is the internal interest rate you use in the company?
What is your predicted future market demand?
Does the output vary much due to market fluctuations, seasons or other factors, and if so what are these factors?
What is your desirable over capacity?
Is some of that capacity transferable to some other usage? If so, what is the rescheduling cost?
Is some of your production ever handled by subcontract production? If so, what is the cost?
Do you ever lose revenue because you cannot meet orders due to shortage of capacity?
When you have production stops, how long do they usually last and what is the reason for them? Do you ever have planned such stops? If so what is the planning cost?
If you expand a line in order to increase capacity what is usually the cost for the machines?

Questions to FlexLink

How big is the estimated initial investment of DAS?
What are the predicted numbers for all the above questions using DAS?
Floor space cleared with DAS?

Questions to company X

Purpose of the visit

The purpose of the visit is to examine what effects on production and especially production costs the introduction of FlexLnk’s Dynamic Assembly System had at company X. The situation before the introduction is to be compared with the present situation.

Information needed

General information
What was the reason for introducing DAS at company X?
What kind of system did company X use before?
What kind of products does company X produce using DAS?
Do company X produce the same kind of products today as was being produced prior to the introduction?

The introduction
How would you describe the introduction phase?
How was the introduction planned and executed?
For how long did the change from the traditional system to DAS last?
What were the estimated costs of introducing DAS? These would be costs related to production delays, excess capacity, necessary education, ramp-up and so forth.

Production related aspects / basic information
The questions from here on concern production prior to introduction as well as production using DAS.
Number of products produced
Number of employees
Number of different products
Number of product variants
Number of new products introduced and also changes to existing products
Use of capacity
Productivity (percentage of value-adding time)
Number of production stops
Used square meters of factory – if less today in what way is the excessive space used.
Number of failures
Cycle time
Number of automated production steps and number of manually executed steps

Production system
What are the main differences between the production today and the production prior to DAS?
What are the similarities?

Production costs
What is the ratio between fixed and variable costs?
What are the variable and fixed costs per produced product?
By what parts are the fixed and variable costs composed?
What are the costs of introducing a new product or a new variant of an existing product?
What were the cost savings from using DAS? What is included in such a calculation?
Have you been able to estimate cost savings that are related to the fact that DAS easier handles new products and variants and also more variants produced within the same system?

Quality and information
What kind of information is documented?
In what way is the information documented?
Who uses the information and for what purpose?
How is the system controlled and managed?
In what way is quality secured?
What is the cassation ratio?
Is the number of failures on a steady level?

Employee management
What are the requirements that the employees have to fulfil?
At what level do the employees and management appreciate ergonomics?
Using DAS, do the employees find their work more attractive and stimulating?
What was the need for education on DAS?