Comparative Study of Automation Strategies at VW Germany and South Africa

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Foreword

This work forms the conclusion of my engineering studies, entitled “Magister Technologiae: Industrial Engineering” (M Tech Ind Eng), in the Department for Industrial Engineering for the Nelson Mandela Metropolitan University (NMMU). It was written in the Volkswagen AG Wolfsburg in the department Start-up and process optimisation. This work gave me an insight into the whole vehicle manufacturing, especially into the assembly lines in Wolfsburg and Uitenhage, South Africa. Writing a technical work in English as a foreign language was a special challenge for me.

On the way I want to thank my promoter Mr Prof. Dr. Eng. Igor Gorlach for his enormous support. In every situation, he gave me information to enable me to carry out this work. To the same extent, I want to express my thanks to six students of the Start-up and process optimisation. They supported me and engaged in my efforts to get data and to develop solutions.

Furthermore, I thank my supervisor Mr Prof. Dr.-Ing. Holdack-Janssen. Thanks to Mr Gibbons for supporting in English formulations and modes of expression.

Finally, I want to thank all supervisors and employees, who provided the necessary data for this analysis. All of this support contributed to me writing this work.

Oliver Wessel   Wolfsburg, August 2006

Declaration of academic honesty

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List of abbreviations

AG	***A**ktien**g**esellschaft*
Anon.	**Anon**ymous
AP	**A**ssembly **P**art
BI	***B**etriebs**i**ngenieur*
CC	**C**ontrol **C**ircles
Chap.	**Chap**ter
CIM:	**C**omputer **I**ntegrated **M**anufacturing
CP	**C**heck**p**oint
CW	**C**onstant **W**iderstand
DIN	***D**eutsche **I**ndustrie **N**orm*
DIN EN ISO	***D**eutsche **I**ndustrie **N**orm **E**uropa **N**orm **I**nternational **O**rganisation for **S**tandardisation*
DIN ISO	***D**eutsche **I**ndustrie **N**orm **I**nternational **O**rganisation for **S**tandardisation*
DM	***D**eutsche **M**ark*
DRR	**D**irect-**R**unner **R**ate
E&Q	***E**ignung & **Q**ualifizierung*
FA	***F**ertigungs**a**bschnitt*
Fig.	Figure
FISeQS	***F**ahrzeug**i**nformations**s**ystem **e**lektronische **Q**ualitäts**s**icherung*
FMEA	***F**ehler **M**öglichkeiten **E**influss **A**nalyse*
Glass	**Glass** trouble cases
GmbH:	***G**esellschaft **m**it **b**eschränkter **H**aftung*
H	**H**all
HDT	**H**and-**D**ata **T**erminal
IE	**I**ndustrial **E**ngineering
IS	**I**nternal **S**ervice
K-QS	***K**onzern **Q**ualitäts**s**icherung*
KB	***K**arosserie **B**and*
KVP	***K**ontinuierlicher **V**erbesserungsprozess*
Mecha	**Mecha**nical trouble cases
n.a.	**n**ot **a**vailable
n.d.	**n**o **d**efects
NFT	***N**ull-**F**ehler-**T**or*

OEE	**O**verall **E**quipment **E**ffectiveness
PA	***P**roduktions**a**bschnitt*
PWA-V	***P**roduktion **W**olfsburg **A**utomobilfertigung-**V**orserie*
Q	**Q**uality
QA	**Q**uality **A**ssurance
QAS	**Q**uality **A**ssurance **S**ystem
QC	**Q**uality **C**ircle
QCC	**Q**uality-**C**ontrol **C**ircle
QCG	**Q**uality-**C**ontrol **G**roup
QE	**Q**uality **E**ngineering
QM	**Q**uality **M**anagement
QRK	***Q**ualitäts-**R**egel-**K**reis*
QUASI-FI	***Qua**litätssicherungs- **S**teuerungs- und **I**nformations**s**ystem **F**eld**i**nformation*
QW	**Q**uick **W**in
SA	**S**outh **A**frica
SBBR	***S**ignalleuchten für **B**remslicht, **B**linker und **R**ückwärtsgang*
SF	***S**chadens**f**all*
Tab.	**Tab**le
TE	**T**echnical **E**ngineering
TPS	**T**oyota **P**roduction **S**ystem
TS	**T**echnical **S**ervice
TQC	**T**otal **Q**uality **C**ontrol
TQM	**T**otal **Q**uality **M**anagement
TÜV	***T**echnischer **Ü**berwachungs**v**erein*
TVM	***T**echnik **V**ormontagen*
USA	**U**nited **S**tates of **A**merica
VIN	**V**ehicle **I**dentification **N**umber
VPC	**V**ehicle **P**reparation **C**entre
vs.	**v**er**s**us
VW	**V**olks**w**agen
WFM	***W**agen **F**ertig**m**ontage*
WOB	***Wo**lfs**b**urg*
ZP	***Z**ähl**p**unkt*
ZWT	***Zw**ischen**t**akt*

1. Introduction

Today, the automotive industry is the epitome of mass production, mass marketing and mass consumption.[1] Production technology becomes more significant due to the ever-growing number of suppliers and competitors in the market. Increasing globalisation causes stronger competition among the producing companies. Markets convert from sales to consumer markets. Assembly with a high-value-creating portion and direct reference to customers gains more importance, because these days, customers demand recently updated and individualised products.[2]

To reach a strong position in the market and to commit the customer to a company, efforts are taken to design specialized products for individual customer needs. This results in an increase of quality, functionality and numbers of variations with a simultaneous fluctuation of numbers of units and a reduction of batch sizes. Customer demands for a rise in a complexity of products are also a consequence.[3]

The assembly is the last step of the product manufacturing on which the customer has the strongest impact. Today’s production cannot influence the market. It has to adjust to the demands of the market as soon as possible. The product also needs to be manufactured in any variation as fast as possible. Therefore, present companies have a fast ability to react to changing situations with flexible and innovative management.

Multiplying dynamic demands, as the increasing numbers of variations, require maximum supply assurance. A large diversity of products has to be provided as soon as possible, whereas the lifespan of products is still being reduced. Flexibility is required in all fields of the company as well as a consequent reduction of the turnaround time.[4] More investments in new production technologies increase the production capacity, which leads to limitations in product innovations as a consequence. As a result, production technologies have to be tied down so that demands of capacity can be fulfilled and the manufacture is competitive. Wrong technology leads to a loss of advantage in the competition and a high strain on fixed costs. One-sided orientation towards particular areas in the competition is not sufficient for the long-term securing of a company. Hence, various parameters need to be optimized simultaneously. [5]

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[1] See Glauser 2005, pp. 2
[2] See Lotter 1998, pp. 131
[3] See Lotter 1998, pp. 131
[4] See Lay 2001, pp 399-400
[5] See Hartmann 1993, pp 1

Striving for rationalisation is influenced by the compulsion for a fast, flexible and economical production.[6] The targets of rationalisation are to increase the production potential and to decrease costs, so that productivity and competition rise. Rationalisation can be achieved through a higher input of capital, which leads to more automation.[7]

Hence, an urge for progressive automation arose in the past, since it seemed to be the only strategy to stay competitive.[8] Prices of components in automotive technology decrease with rising productivity. Automation was introduced to increase the quantity, to reduce the rate of waste and to reach a steady and higher product quality. But companies have had more and more difficulty in reducing turnaround time and capital freeze and in making full use of the expensive resources and equipment.[9] Ongoing automation has caused expensive over-engineering. Therefore, deautomation becomes a mode for reducing the expenses of manufacture.[10]

Higher automation to increase productivity is limited because of complex assembly processes and problems with variants and numbers. Therefore, deautomation is an alternative for increased product flexibility.[11]

Decreasing batch sizes cannot be digested economically with highly automated machines. The necessary flexibility towards variations of capacity, which comes from variations of sales, is not given in highly automated machines. Therefore, deautomation leads to more flexible capacity.[12]

Automation is temperamental. Therefore, deautomation is the chance for more availability. Furthermore, deautomation has become more popular in the last years because of shorter product life cycles, smaller investments and a better use of employees' qualifications.

As can be seen, a dominance of the negative effects in vehicle assembly has reached full attention in recent years. Consequently, a rethinking process has to start here, so that problems in production can be solved by an automated concept. 36% of the companies, which have had experiences with automated solutions, are of the opinion they exaggerated automation in the past.[13]

This assumption will be examined for the Volkswagen AG in this master thesis. That is why the following task formulation in Chapter 2 has been created.

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[6] See Hartmann 1993, pp. 3
[7] See Ross 2002, pp. 2
[8] See Lay 2001, pp. 399
[9] See Hartmann 1993, pp. 3
[10] See Lay 2001, pp. 399
[11] See Alber 1999, pp. 426
[12] See Lay 2001, pp. 403
[13] See Lay 2001, pp. 400

2. Task formulations

This master thesis analyses the Volkswagen assembly lines of the Golf A5 manufacture in the mother plant in Wolfsburg, the Touran manufacture in the Auto 5000 GmbH in Wolfsburg as well as the Golf A5 manufacture in Uitenhage in South Africa - all with regard to the level of automation. The target of the analysis is the determination of the optimal level of automation in the three production sites and therefore, the investigation of the potential to automate, or rather to deautomate in particular sections of the assembly in the prevailing production locations. The three production sites are to be investigated with regard to costs, quality and quantity.

The master thesis has been set up according to the following structure:

After the general presentation of the company Volkswagen and the presentation of the three examined production sites, the basics have to be described on which the concept will be founded. First, the general basics of automation and the level of automation have to be demonstrated. After that the particular basics of costs, quality and quantity have to be shown. Because of the complexity and the large scale of the project, it is advisable to explain the particular basics separated from each other. The basics of costs shall inform about the relevant cost and investment calculation epitomes. Basics about quality should explain how quality is defined and to what extent quality is influenced by automation and employees. The basics of quantity have to give an overview on production figures and indexes of different automation strategies.

In a further step, the examinations of each production site have to be carried out. To enable this, the examined area has to be marked out and afterwards a suitable process is to be developed to determine the optimal level of automation with regard to costs, quality and quantity. The collected solutions have to be assessed critically and continuing examinations and considerations have to be carried out.

In the next step, the solutions and results of costs, quality and quantity have to be combined to one total result for each production site.

After summarising and comparing the results, recommendations that lead to optimal levels of automation have to be mentioned to enable an optimisation procedure, which is valid for any production site of the company.

The following figure shows an overview of the procedure for obtaining the results.

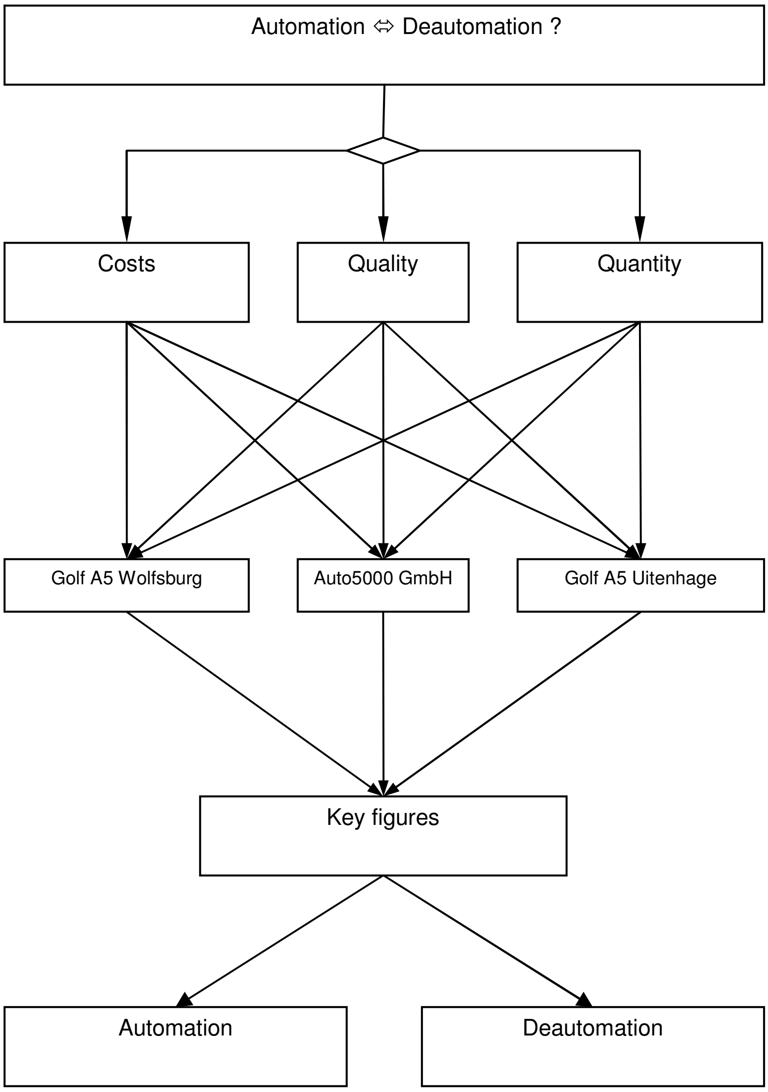

Fig. 2.1: Procedure to obtain the results
Source: Own presentation

3. Presentation of the company

On the 28th of May in 1937, Volkswagen was set up. Its head office is in Wolfsburg. Today Volkswagen AG is Europe's biggest vehicle manufacturer. In the year 2005 Volkswagen AG sold 5,243,000 vehicles worldwide. This means a motorcar share on the world market of 9.1%. The company made a turnover of € 95,300,000 and a profit of € 1,120,000 after tax.[1] As can be seen in Fig. 3.1, the motorcar business is divided into the two brands of Volkswagen and Audi with a product range from small motorcars to luxury models and sports vehicles. Volkswagen has got 44 production sites in 18 countries worldwide and a workforce of 345,000 (179,000 in Germany).[2] Volkswagen AG has a range of 92 different vehicles company-wide from small motorcars up to trucks in different derivatives. Volkswagen alone has a range of 28 different vehicle types.[3]

Segment	**Automobiles**				**Financial services**
Business segment	Brands Volkswagen	Brands Audi	Industrial-vehicle	Other groups	Financial services
	VW-Motorcars Skoda Bentley Bugatti	Audi Seat Lamborghini	VW-Indusrial-vehicle	Financing Business service	Leasing Insurance Fleet sales Financing

Fig. 3.1 Structure of Volkswagen AG
Source: Anon. (Volkswagen AG)

In the mother plant in Wolfsburg, the Golf A5, Golf Plus and Golf A4 Variant are produced on three different assembly lines. The Touran is produced in the Auto5000 GmbH on one assembly line, which is integrated in the mother plant in Wolfsburg. The Auto5000 GmbH was set up in 2001, where compared to the Volkswagen basic pay, 5,000 people were employed for a gross wage of DM 5,000. The working hours are 35 hours per week for 5 days, which is clearly longer than the 28.8 hours per week for 4 days, which is the standard pay scale calculation of Volkswagen.[4]

The mother plant has a size of 6 km^2. It is the biggest automotive factory in the world. The maximum plant capacity is about 4,000 units per day.[5]

In the plant in Uitenhage the Caddy, the Golf A1 (City Golf), the Golf, the Jetta A5 and the Polo A04 are produced as well as 3 versions of the Volksbus in 3 model ranges and the VolksLkw.

The plant has a size of 0,5 km^2. The maximal plant capacity is about 450 units per day. The working hours are 40 hours per week for 5 days.[6]

[1] See Anon. (Volkswagen AG)
[2] See Anon. (Volkswagen AG)
[3] See Anon. 2006, pp. 40
[4] See Anon. (IG Metall)
[5] See Anon. 2006, pp. 40
[6] See Anon. (Intranet VW South Africa)

4. Basics

This chapter is about the basics, which are necessary for the analysis. Automation means the use of artificial equipment, so that a process runs either fully or partly automatically, without the collaboration of people. For an assembly facility it means to be equipped with automats, so that it works automatically. Automation is the result of automating.[1] It describes the self-confident controlling of functions. Thus, the following points are targets of automation:[2]

- Reaching a continuously high manufacturing quality
- Improving the competitive ability
- Decreasing the production costs to stay competitive
- Controlling the demanded numbers of variation
- Reducing innovation cycles and turn around time
- Developing robust production systems with higher flexibility at changes

But in the recent time it has been shown that these targets cannot always be achieved exactly, whereas often there are demands for the automation of particular processes for social reasons, even though they cause high costs.[3]

An assumption for automation is that the available parts have to be positioned as precisely as possible, so that the robot is able to work on them properly, which of course causes higher expenditures. Furthermore, the product, which has to be mounted, must be constructed for an automated mounting. The employee is able to reconcile little mistakes economically, like wrongly fitted parts, by using his sense, hands and experience. Compared with that, machines often cannot solve these problems. They can only report disturbances and require interventions of personnel in the usually automated assembly process.

The level of automation represents the part of automated functions of a system in relation to the complete function of the system. The more functions of a system are automated, the higher the level of automation is. It is calculated by the quotient of the number of automated functions and the total number of functions. In order to realize this, all functions must be synchronized. The level of automation has to be optimally determined according to technical, economical and social factors. At present, fully automated machines can mostly be used for a very high number of units. Therefore,

[1] See Ross 2002, pp. 11
[2] See Favre-Bulle 2004, pp 8-9
[3] See Löhr 1977, pp. 47

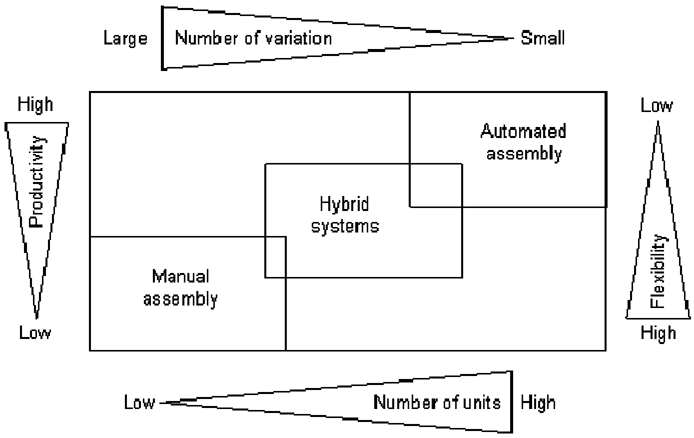

Fig. 4.1: Ranges of application for different assembly concepts
Source: Lotter 1998, pg. 103

hybrid workplaces give the possibility of adjusting the whole range from a low to a high level of automation. In the hybrid assembly systems (see Fig. 4.1) the mountings are partly automated and partly manual, which means that automated stations are combined with manual stations. Therefore, it combines the advantages of the manual with the advantages of the automated assembly. By optimising the level of automation the right ratio of automation and use of employees is fixed. But to avoid stress situations, the manual workplaces should be decoupled from the cycle of automated facilities. They have to fulfil the demands of human workplace design. Another advantage of hybrid systems is to expand the system adapted to the number of units during the whole time of use. So, the risk of disinvestments can be avoided.

Furthermore, a changed level of automation has consequences for the qualifications of employees in the areas of burden and job-related stress as well as in the task structure.[4] Higher automation causes the redundancy of employees, and redundancy depends on the workers' qualifications. The lower the qualification, the stronger is the threat of automation.[5] For the modification of the qualification structure the following different theses exist:[6]

- **Higher qualification thesis**: Higher automation needs highly qualified employees, especially in maintenance, where few experts are needed for fastidious tasks and employees are required for acquired routine tasks.
- **Disqualification thesis**: Higher automation evokes lower and one-sided qualification requests.
- **Polarisation thesis**: A small group of highly qualified employees stands opposite to a large number of low-qualified personnel.

The effect of qualification and automation cannot be decided in general form. Therefore, there is no inevitability between qualification and automation. To modify the task

[4] See Corsten 1995, pp. 7
[5] See Corsten 1995, pp. 244
[6] See Corsten 1995, pp 244-245

structure, it will be mentioned that existing working structures would need to be divided. With higher automation, the movement of tasks is combined with specialisation.[7]

After this short description of automation and the level of automation, the following chapter will give an introduction of the costs.

4.1 Basics of costs

This chapter describes the basics of the costs as well as their definitions and methods. The description of all existing methods of cost calculation will not been carried out. Advantages and disadvantages of the individual methods have been discussed sufficiently in literature. Hence, only the basics of costs and the methods are discussed, which are necessary for this thesis.

4.1.1 Basics and definitions

Costs are the assessed use of commodities and business services to produce and sell operational outputs as well as to keep up the capacities that are necessary to do this.[8]

The main task of **cost calculation** is to record all arising costs and outputs over a period of time and to determine the trading results from them. The cost model has to be created in as much detail as possible, but also as simply as possible and problem neutral.[9] The aim of every company is the principle of minimising costs in the production, which means the production that causes the least costs is optimal.

In the cost calculation there is a difference between **direct expenses** and **general expenses**. Direct expenses can be assigned to individual units of account depending on what caused the costs. In contrast, general expenses cannot be subdivided according to that principle, because they have to be assigned to many periods or cost centres. Besides, there are unreal general expenses, which can be subdivided into individual outputs, but this has not been done because of straightforwardness and economy.[10] By growing automation there is a postponement from direct to general expenses, because of decreasing wage-direct expenses and increasing capital costs, but also control, supervision and maintenance costs.[11]

[7] See Corsten 1995, pp. 245
[8] See Hartmann 1993, pp. 7
[9] See Hartmann 1993, pp. 34
[10] See Haberstock 2002, pp. 57
[11] See Hartmann 1993, pp. 36

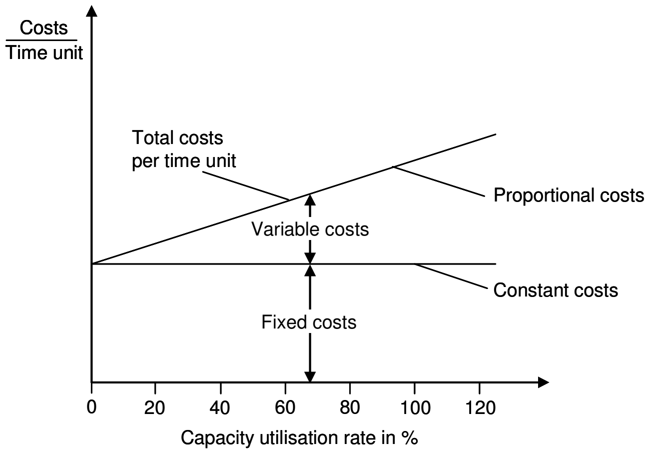

Fig. 4.2 Cost course depending on the capacity utilisation rate
Source: Fichtmüller 1996, pp. 42

Apart from the mentioned distinction it is possible to subdivide costs into **variable costs** that grow with the produced number of units either proportionally or progressively or even digressively, and into **fixed costs** that do not react to changing activities or produced quantities.[12] Besides, there are costs staying unchanged and jumping to a higher level. These costs are called jump fixed.[13] In Fig. 4.2 on the following page proportionally variable and fixed costs are shown depending on the capacity utilisation rate of the machines.

Fixed costs stand the continuation of the company in the form of imputed depreciation, imputed interest charge and costs for equipment, rooms and cyclical inspections of machines. Variable costs can be costs for remaining maintenance, energy for machines and operating supplies.[14]

To calculate the total costs, the fixed and variable costs have to be added up:

$$C_{tot}(n) = C_{fix} + C_{var} = C_{fix} + c_{var} \cdot n \qquad [€] \qquad (1)$$

C_{tot} = total costs [€]
C_{fix} = fixed costs [€]
C_{var} = variable costs [€]
c_{var} = variable costs per unit [€/unit]
n = number of units [unit]

With increasing automation, the proportion of variable costs decreases and the remaining block of fixed costs increases. However, with a large block of fixed costs, statements about economically practical behaviour are not possible, because the effects of alternatives cannot be made visible. The changes in the block of fixed costs cannot be put down to its influences.[15] Hence, high automation makes it more difficult to identify high causal agents of costs and to lower them.

[12] See Fichtmüller 1996, pp. 41
[13] See Corsten 1995, pp. 84
[14] See Fichtmüller 1996, pp. 41
[15] See Kaiser 1993, pp. 26

For deducing rationalisation potentials, the costs per unit are relevant, because of the dependence between costs and amount of production.[16] Costs per unit can be achieved by dividing the total costs by the amount of production. With increasing activity the fixed costs per unit decrease, as can be seen in Fig. 4.3. This effect is called **digression of fixed costs**. The total costs per unit have a reciprocal course.

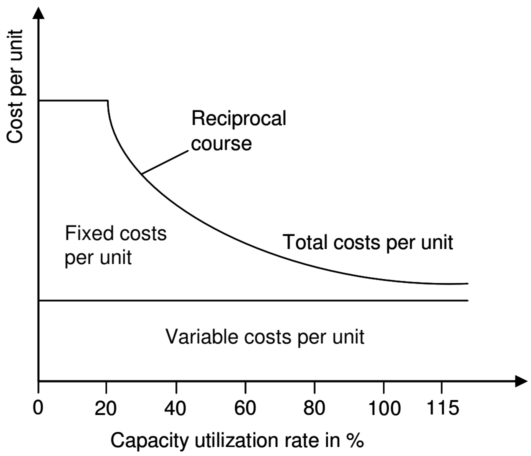

Fig. 4.3 Costs per unit course, depending on the capacity utilisation rate
Source: Fichtmüller 1996, pp. 43

The following formula describes how to calculate the costs per unit:

$$c_{tot}(n) = \frac{C_{fix}}{n} + c_{var} \qquad [€/unit] \qquad (2)$$

c_{tot} = total costs per unit [€/unit]
C_{fix} = fixed costs [€]
c_{var} = variable costs per unit [€/unit]
n = number of units [unit]

Lowering the costs per unit is possible by reducing fixed costs, by reducing variable costs or by increasing capacity utilisation of the assembly system, which is shown in Fig. 4.4. A reduction of fixed costs can be done by making a more reasonable purchase of assembly equipment for new investments or by technologically differently structured assembly equipment.[17] Reducing the above-mentioned variable costs as well as the variable personnel costs can do a reduction of variable costs. If these costs are optimised already, the only possibility is to lower the wage costs.[18] Increasing the capacity utilisation is possible by the optimisation of the total time used by the equipment. This time is separated into the really used time and the time where the machines stand idle.[19] This time is called **down time**. Fig. 4.5 shows the relationship of really used time and down time. As can be seen, most of the maximum holding time usually is down time and only a tiny part is used for production.

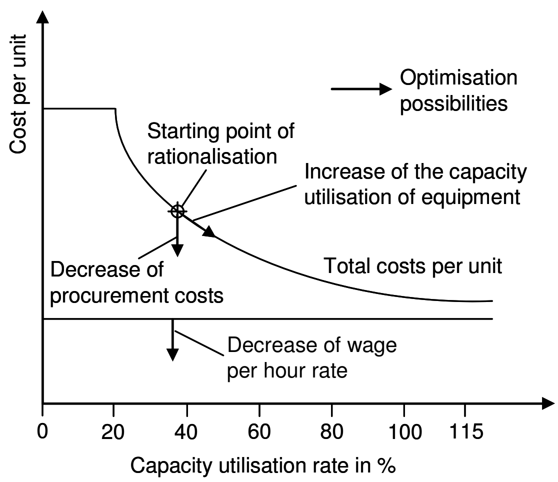

Fig. 4.4 Possibilities to reduce costs per unit
Source: Fichtmüller 1996, pp. 44

[16] See Fichtmüller 1996, pp. 42
[17] See Fichtmüller 1996, pp. 44
[18] See Fichtmüller 1996, pp. 45
[19] See Fichtmüller 1996, pp. 45

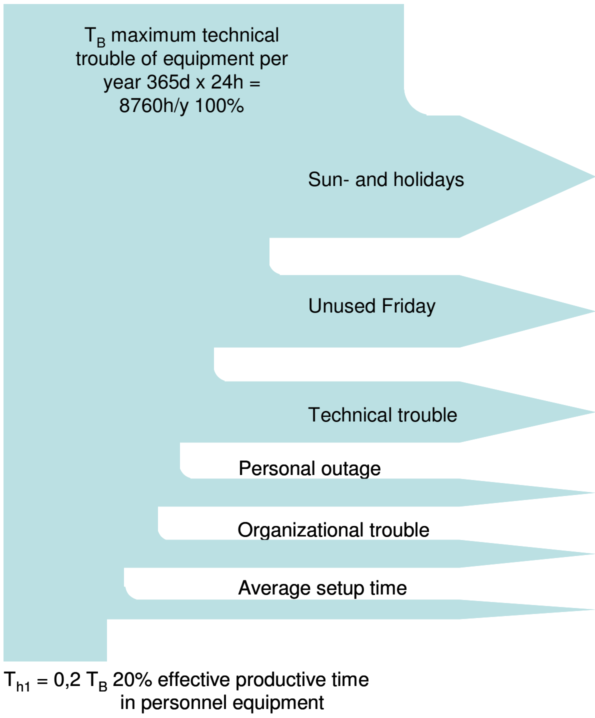

Fig. 4.5 Sorts of down times
Source: Fichtmüller 1996, pp. 46

Hence, there is much potential. But there is a conflict between the capacity utilisation and customer demands in the market. If no products are required, there is no sense for manufacturing.

The total costs per unit depending on the level of automation are presented in Fig. 4.6. Through it, other costs factors, like general expenses or material costs, are left out for a better overall view. As can be seen, the direct wage costs decrease proportionally with the growing level of automation. The course of the costs per unit of automation investments, including consequence costs, runs progressively because in gradually increasing the level of automation, first the simple and economical functions will be automated. Further on, the expenditure increases over-proportionally, because of the rising complexity of the system. The necessary care of the assembly systems and the more detailed work scheduling are especially reasons for this effect.[20] Generally, the course of the total costs per unit shows a minimum because of the contra-rotating courses of automation investments and wage costs. This is the economical optimum. Other influences, like quality or quantity, possibly show other optima, so that a compromise has to be found for the implementation of the optimal level of automation.

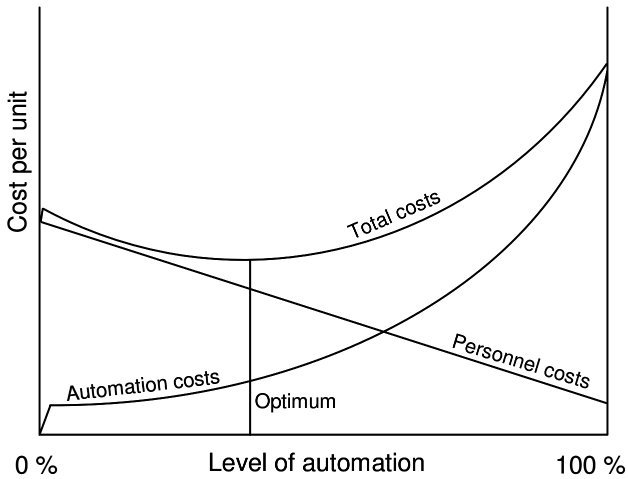

Fig. 4.6 Costs per unit vs. level of automation
Source: Fichtmüller 1996, pp. 7

After showing the basics and the definitions of costs and their connections to the level of automation, the next chapter describes briefly the cost calculating systems before the resource attempt is explained in particular.

[20] See Fichtmüller 1996, pp. 7

4.1.2 Cost calculating systems

Cost calculating systems are systems that enter, save and analyse costs after set rules have been advanced, which are aligned with the tasks of cost calculating.[21] The **partial-cost calculation** sets off only a certain cost of a period against costs per units (cost unit=Kostenträger or unit cost=Stückkosten). Compared with that, the **full-cost calculation** reschedules all incurring costs of a period to cost units. Therefore various types of costs are differentiated. For the assessment of an assembly system, only the costs that are influenced by this system have to be included. This fact leads to the resource attempt, which is described in the following chapter.

4.1.3 The resource attempt

The resource attempt is a **cost-type accounting**. The term **"type of costs"** describes the naming of costs with the same features. For determining types of costs different features can be used, in this case the resource attempt. The advantage of this attempt is that the consumption of values can be shown on the basis of a few convincing types of costs.[22] Through it, only the relevant cost parts are important for this thesis. That means, only a part of all incurring costs are taken into consideration.[23] In the popular literature it is also well known as the relevant cost approach.[24] For this thesis, relevant costs are all costs that change by changing the level of automation. The other costs that do not change can be excluded from the calculating, because they will not influence the result.

The first step of the resource accounting is to divide the costs into different resources. The following six **resources** are necessary for the realisation of the assembly process:[25]

- **Personnel**
- **Operating material**
- **Material**
- **Space**
- **Information**
- **Remaining costs**

[21] See Haberstock 2002, pp. 171
[22] See Hartmann 1993, pp. 75
[23] See Hartmann 1993, pp. 74
[24] See Fichtmüller 1996, pp. 41
[25] See Hartmann 1993, pp. 57

In the following paragraphs, these six resources will be described in detail. Later on, in Chap. 5.1.1, these six resources will be analysed exactly. Then, the relevant parts of each resource will be deduced.

Personnel:

Personnel activities comprise the realization of both line activities and planning activities within the assembly process. The result of this is that the labour costs take a part of the variable costs especially in Germany. Because of this, personnel are the most valuable resources. Personnel are primarily involved in mounting activities, such as the connecting of components, but also provision, cleaning, operating and checking, as well as the indirect activities, maintenance and service, as well as the disposal activities, planning, industrial engineering, quality assurance, controlling and logistics. Disposal costs are mostly listed as bonus of general expenses, which has to be broken down to direct expenses.[26]

Personnel costs consist of wages or rather salary and social costs, which are also called add-on costs.[27] Personnel costs essentially depend on the qualification.[28] Reference unit is the time, because the incurring wage costs for a certain operation are determined by work with given qualification.[29]

Operating material:

Operating material describes installations for assembly and transport. These are connecting and operating systems, facilities and tools.[30]

Operating-material costs include all costs for running the operating material.[31] Therefore imputed depreciations are relevant, because machines are subject to a decline in value for various accounting periods. This decline arises from use, resting, abrasion or technical overhauling. Imputed depreciations should quote the real value consumption and therefore costs that are assigned to its causal agent. In every period a continuous burden is striven for, which causes a linear depreciation.[32]

Besides depreciations, material costs for maintenance and service, energy costs for the operating material and planning costs for external companies belong to this

[26] See Hartmann 1993, pp. 59
[27] See Klose 2006, pp. 24
[28] See Hartmann 1993, pp. 75
[29] See Hartmann 1993, pp. 86
[30] See Hartmann 1993, pp. 59
[31] See Hartmann 1993, pp. 77
[32] See Klose 2006, pp 25-28

resource. Reference unit is the time for the duration of the machine and operating-material use.[33]

Material:

Material is subdivided into the following:

- **Raw material**, which moves as main part into the production.
- **Auxiliary material**, which also moves into the production, mainly as general expenses for auxiliary functions (e.g. screws).
- **Operating supplies**, which exclusively consist of general expenses, for instance water, fuels, coolants and lubricants.[34]

All these kinds of material create costs.

Sometimes additional costs arise by special demands of automated mounting processes to the structure of material. For instance, special mounting-justified screws are needed.[35]

The **capital freeze** of products in stock causes cost increases, too. If manufactured products cannot be sold because of too few customers, they have to be stored, which causes capital freeze. Usually, the production costs are estimated. The costs of capital freeze result from them combined with the calculated rate of interest. It is relevant for the opportunity costs of the capital freeze that arises by contributing capital to the company instead of investing profitably in a different way.[36] Costs of capital freeze also arise in buffer stocks that are needed between the assembly lines. Reference unit of this resource material is either the weight or the number of units.[37]

Space:

Space costs include the area of operating material, the space of operation, the area of tracks, the area for provision of material, the working area and other areas for service and maintenance purposes.[38] They describe all costs to maintain the buildings and areas.[39] Apart from the costs for operating material, imputed depreciations are relevant for the space costs, too. Reference unit is the area in m², because the demands of space costs can be made directly by dimensions.[40]

Information:

[33] See Hartmann 1993, pp. 86
[34] See Hartmann 1993, pp. 60
[35] See Hartmann 1993, pp. 77
[36] See Olfert 2003b, pp. 125
[37] See Hartmann 1993, pp. 87
[38] See Hartmann 1993, pp. 60
[39] See Hartmann 1993, pp. 77
[40] See Hartmann 1993, pp. 87

Information includes both software and hardware. With assembly processes becoming more complex, computer aids are necessary to establish software and hardware, and to run information processing.

Costs for information include all costs to get the required software and hardware. Mostly, these costs are general expenses.[41]

Remaining costs:

Remaining costs are especially the **quality costs**. The quality of products can change with the level of automation, because robots mostly contain a higher repetitive accuracy than people. But, robots are clearly inferior to people who are more flexible in recognizing mistakes and reacting to them. As can be seen in Fig. 4.7, quality costs are usually divided into:[42]

- **Prevention costs** (quality planning, data analysis)
- **Appraisal costs** (test, inspection)
- Internal and external **failure costs**

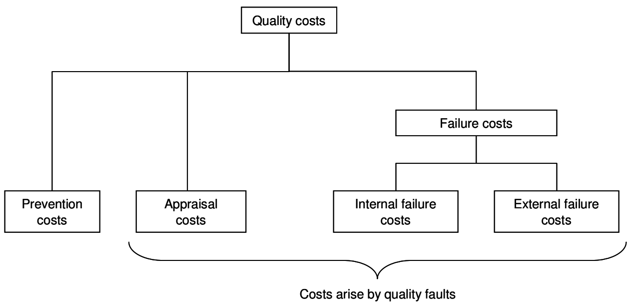

Fig. 4.7 Quality costs
Source: Corsten 1995, pg. 155

Furthermore, costs for the standstill of the operating material belong to this resource.

The result of the resource accounting is the drawing up of all costs that can be expected, subdivided into resources.[43]

4.1.4 Cost comparison calculation as static method of the investment calculation

To assess the automation concepts economically the investment calculation is relevant as well. In the literature, different methods, which are divided into **static** and **dynamic methods**, are explained in detail. Static methods are focused on a moment, dynamic methods on a period of time.[44]

Large investments, like choosing, getting and building up assembly lines in the automotive industry, considerably influence profitability, solvency, security and independence of the company. The following points of the investment decision have to be considered:[45]

[41] See Hartmann 1993, pp. 60
[42] See Tomys, pp. 37
[43] See Hartmann 1993, pp. 112
[44] See Klose 2006, pp. 50
[45] See Staehlin 1992, pp. 12

- long-term capital freeze
- increased fixed costs
- complexity of the obtaining and reporting of data

So, investments have a long-term effect with respect to future planning, because the expected use does not directly occur at the same time of the investment decision, but later. The return on the capital employed comes back to the company only by revenue and depreciations. So, there is a danger of disinvestments, if the revenues do not cover the applications. The decision to invest is the more uncertain the more long-term it is designed for, because fluctuations on the market and therefore, forecasts, are getting more uncertain.[46]

Dynamic methods take several periods into consideration, static methods only one. The period of time cannot be chosen arbitrarily, but has to be adjusted to the useful life.[47] To carry out a cost comparison calculation, the costs of the different investment objects are compared with each other. The investment object, which causes the lowest costs, can be chosen. Proceeds are not, and should not be, taken into consideration. Because of this, it is left open, if the most reasonable solution makes profit. The following preconditions have to be fulfilled for using the cost comparison calculation:[48]

1. Objects have to have earnings at the same level.
2. The production quality of the objects has to have the same level.
3. The objects have to be served for rationalisation investments.
4. Objects have to have different investment alternatives

The more extensive the cost comparison is (including all capital and running costs) the better the result is.

The cost comparison can occur per period or per output unit. In the cost comparison calculation, the methods of cost calculation are used.[49]

[46] See Klose 2006, pp. 52
[47] See Götze 2002, pp. 50
[48] See Olfert 2003a, pp. 83
[49] See Olfert 2003a, pp. 84

4.2 Basics of quality

In this part quality and all related aspects are explained. Quality is a key factor for a secure existence and a future, if it is integrated into all the processes in the company.[50] So today, quality is rated as a top priority competition factor.[51]

4.2.1 Definition of quality

Definition according to DIN 55350:[52]

> Quality is the sum of all properties, which an object or activity has to perform to be suitable to serve a particular aim.

A more detailed definition, which can be used for the assembly area, is:[53]

> Quality is the total sum of the features of a unit regarding its suitability to fulfil specified pre-requisites. This unit refers to products and processes as well as to services where the demands of the customer on the product have to be fulfilled. The customer places specified and required demands on the product, which also include process and service.

The quality characteristics of a manufactured product are:

> An assembled product is only of high value and marketable if it fulfils determined quality demands.[54] Therefore the demands of product quality have to be looked at while planning the assembly system.

4.2.2 Quality Control

Quality Control is the comparison of target quality with the actual quality to identify discrepancies (trouble spots).[55] So if differences are identified, selection or rectification and research into the causes are necessary to enable conclusions to be drawn.

Sources of defect are generally differentiated in:[56]

- Situation-dependent error causes
  - Machine-dependent
  - Material-dependent
  - Method-dependent

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50 Tomys 1995, pp. 5
51 Favre- Bulle 2004, pp. 385
52 DIN 55350 1993, 5520
53 DIN/ISO 8402 1992, pp. 14
54 See Löhr 1977, pp. 44
55 See Corsten 1995, pp. 153
56 See Corsten 1995, pp. 154

- Human-dependent/behaviour-dependent error causes
    - Direct environmental-dependent reasons (for example light, noise)
    - Direct human-dependent reasons
        - Lack of knowledge
        - Lack of care, attention, etc.

Hence, every factor employed in production represents a potential source of defects. Therefore it is necessary to have controlling measures. Controlling measures are differentiated between total control and partial control. Total control is a supervision of each part with regard to the relevant properties. Partial control is limited to the supervision of randomly chosen parts (spot-check) out of the whole. Here statistical quality control is also spoken of because the quality level of the whole is concluded on the basis of spot-check results.

There are two ways of looking at Quality Control of products (see Fig. 4.8): as a point of time-dependent or period of time-dependent way. The time-dependent quality refers to the quality of conception and execution in particular. The period of time-dependent quality refers to the reliability of the product.

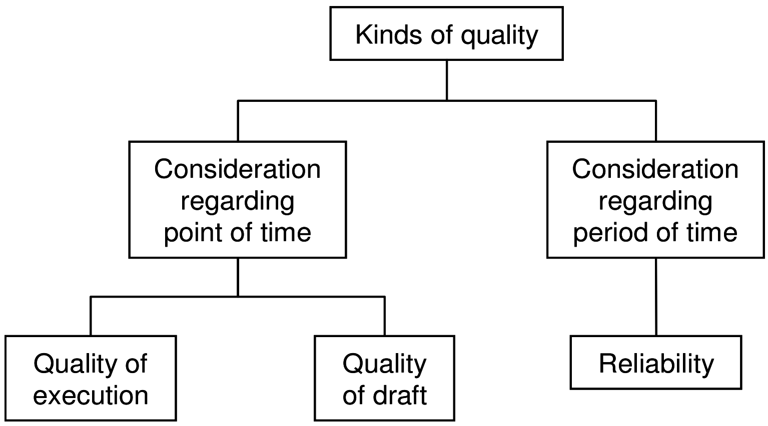

Fig. 4.8: Kinds of quality,
Source: Corsten 1995, pp. 154

4.2.3 Quality management

According to the modern view of quality the satisfaction of external and internal customers is paramount.[57] The aim of the Quality Management (QM) is to achieve business objectives that depend on the realisation of customer demands. The demands have to be guaranteed through all the phases by suitable measures and practical structures of organisation. Each company has to have a more or less fully developed QM.

Owing to the significance of quality[58] the question of the economics of the QM system has to be addressed. In terms of improvement in company efficiency the aims of the QM system have to be in alignment with the company's economic objectives.

[57] See Favre-Bulle 2004, p. 385
[58] See Chap. 4.2

Finding out and processing quality relevant data play an important part. Appropriately, there is a close connection between QM and other management areas. Quality policy determines quality relevant targets and intentions in coordination with company strategy. Normally their definition is the task of the management board (see Fig. 4.9). Concerning the responsibilities of the employees, authorization and competence are determined for the conversion into practice. The Management have to guarantee that quality consciousness and responsibility is lived[59] from top levels of management down to all the workers at the machines.

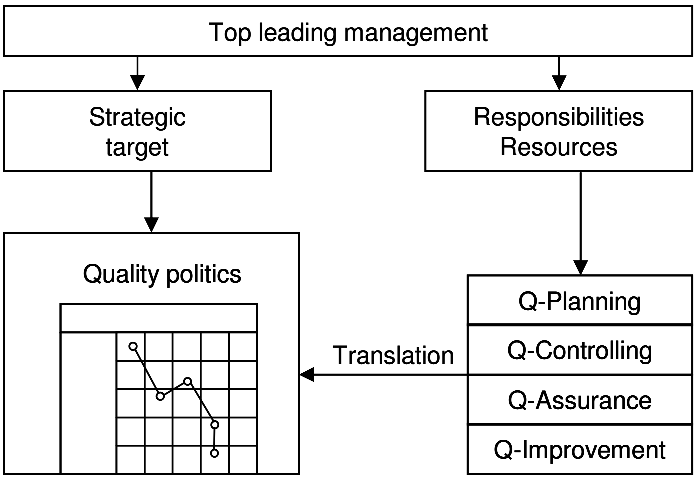

Fig. 4.9: Quality management
Source: Favre-Bulle 2004, pp. 386

In modern QM the principle of personal responsibility for quality is included as a key factor. It is not control from a higher level, which is seen as appropriate today, but the awareness of each employee about his responsibilities and his identification with the company's objectives and the task sections deduced from this. The main duty of Quality Engineering (QE) is it to make instruments, tools, methods and resources available, which enable the employees to realise defined quality objectives.

4.2.4 Quality index determining

Indexes are understood as numbers, which record quantitative counted facts in a concentrated form. An index is formed by the following elements:[60]

- Information character
- Ability to quantify facts
- Specific form of information

These elements make it possible for the user of indexes to classify and assess complex facts on a metric scale. Making an index is only completed, when a clear definition with details of the object under examination and the object of its application is included. All the information included in the index must be adequately defined. The quality of an index mostly depends on the statistics, which forms the basis from which

[59] See Favre-Bulle 2004, pp. 386
[60] See Tomys 1995, pp. 93

the index is determined. To avoid an ambiguous interpretation and a reduction in the information, index systems are formed. Index systems are defined as a compilation of quantitative variables, in which individual indexes belong to each other, supplement or explain each other in an objective, practical connection, and together they are focused on one common paramount target.

The standard of the production process is specified by the quality indexes of the output.[61] For this the quality indexes in manufacturing and assembly are to be examined in particular:[62]

- The quota of quality defects in production that shows the number of units in proportion to the whole production volume, which is not able to fulfil the quality demands straight away.
- Indexes such as the number of rejects and the rectification of rejects, as well as their prevailing share in the whole production volume show the developing trend.

  Frequencies of defects are distinguished and classified according to their different qualities and then put in relation to the total number of defects.
- The number of complaints is an indication of the quality defects that have remained undiscovered in the production process. However, as a rule, there is a time lapse to be expected between the identification of these indexes and the results of other indexes. So, complaints can only be seen in connection with the process output and the factors contributing to their cause.
- Audit-Notes are determined and assessed separately as indexes by each company. These are determined according to stipulated guidelines.

4.2.5 Influence of the employees on quality

In this part the influence of employees on quality is described.

<u>Basics</u>

Mistakes made by the assembly worker are attributable either to a lack of knowledge or to lack of attention.[63] The first instance can be counteracted by training and instruction. But the second is a problem of mentality/attitude to the worker's mistakes, which implies that every worker could reach perfection in his field of activity, if he wanted to.

[61] See Kaiser 1993, pp. 168
[62] See Tomys 1995, pp 103-104
[63] See Corsten 1995, pp. 158

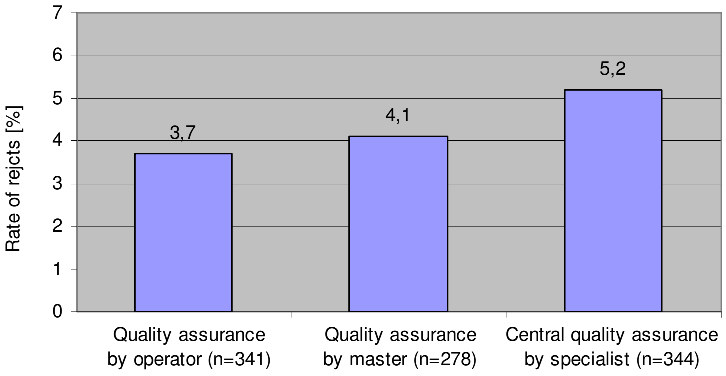

Fig. 4.10: Quality assurance by workers
Source: Gunter 2005, pp. 17

Empirical investigations show, however, that only 20% of mistakes arising are directly influenced by the worker; but 80% of the mistakes which occur can be traced back to by mistakes in planning, material defects, etc.[64]

Other multi-variant analyses[65] confirm a positive connection between a reduction in rejects and quality assurance by the worker. The aim of quality assurance by the worker is to produce quality and not to establish it by checking. The result is an influence on the reject quota (see Fig. 4.10). A significant difference can be seen if you compare the reject quota in companies where the worker controls the quality with the reject quotas in other companies where this form of control by the worker is not integrated into the quality-control system. While in the first mentioned group a mere 3.7% of the manufactured products had to be reworked, the comparable results of the other groups were 4.1% and 5.2%.

<u>Teamwork</u>

An individual work task on an assembly line is, as a rule, a cyclical repetitive activity and the scope of the work is relatively low.[66]

Job rotation is when the workplaces are changed round between the workers due to an initiative or in a certain rhythm. The aim is to relieve the monotony, to reduce one-sided strains and to promote the understanding of operational interrelationships. There is no foreman; he has had to become the group adviser. Conditions for a successful team are a clear set of rules and regulations, strong discipline, mutual reliability, unambiguous targets, a clear description of responsibility areas, transparent information and clearly distributed roles. Teams reduce interfaces and complexity, offer the exchange of experience and concentrate expertise. Leadership is difficult because the leader is not the absolute disciplinary supervisor. The team leader is not able to give orders, he has to convince. Everybody does not only have to master his own role but must also know and understand what the others are doing. The success of a team

[64] See Corsten 1995, pp. 159
[65] See Lay 2005, pp. 36
[66] See Urban 1995, pp. 6

depends on the qualification and motivation of the members. Demands on qualification are a flexible execution of tasks, a considerably expanded range of work, frequent rotation of the workplace, (workers should be able to replace each other), strain variation due to balanced demand structures, material disposal in the team, distribution of tasks by the team, ability to adapt to new variants as team responsibility for quality and deadlines, design of workplaces and work routines.[67]

Ergonomics[68]

Recommendations from ergonomics are taken into consideration in order to realize an optimal working environment for the workers. Some of the things to be taken into consideration amongst others are noise pollution, oscillation pollution, lighting etc. A place of work must be projected according to the 5-Percentil-values to 95-Percentil-values so that the jobs of a part of the population can be managed.

Qualification

Qualification schemes aim at generally improving the commitment of workers to their company. This means integration should be promoted, the identification with the product should be improved and the quality responsibility should be increased.

Qualification measures have to be structured strategically on a medium- to long-term basis. Attention must be paid to qualifying only workers who are capable and willing. Qualification programs subdivided into qualification steps have to be worked out according to the worker's qualification[69] (see Fig. 4.11).

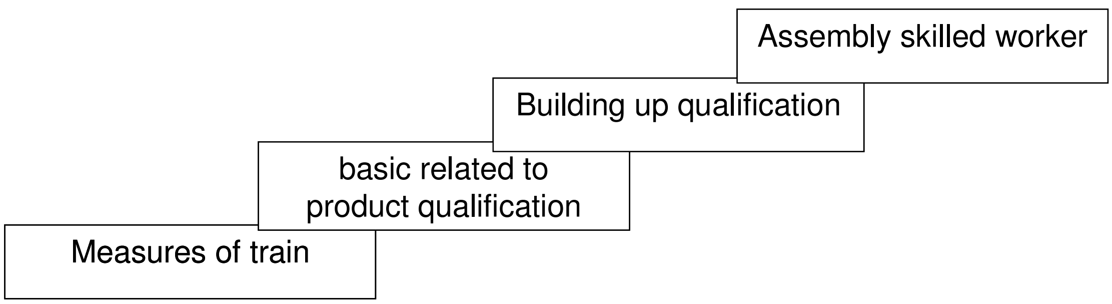

Fig. 4.11: Steps of qualification for workers in assembly
Source: Lotter 1998, pp. 196

- Training measures are limited to the learning of one assembly process. This is mostly the only way of training assembly workers.
- After a basic product-related qualification either the assembly of a complete product or the individual tasks that make up a larger assembly project should be able to be coped . with regard to the expansion of tasks

[67] See Lotter 1998, pp 198 -199
[68] Fichtmüller 1996, pp. 70
[69] See Lotter 1998, pp 196-197

and work concentration on manual assembly. Further qualification should, with regard to the expansion of tasks and work concentration on manual assembly be linked with the supervision of facilities, the prevention and rectification of defects, maintenance and service as well as possible repair work.

- A skilled assembly worker has to have the knowledge of all the usual assembly techniques including basic knowledge of quality assurance, data collection and processing etc. at his disposal.

The phased qualification scheme offers workers the possibility of training, or rather developing their knowledge according to their abilities and willingness.

4.2.6 Level of specific VW knowledge

This chapter describes the quality strategy and politics of the Volkswagen AG. Furthermore, it describes the investigated fields of assembly and the locations in detail.

Volkswagen Group quality policy[70]

With excellent products and services in all brands and companies, Volkswagen Group, as a global player, wants to inspire customers all over the world and reach exceeding company results. This target of Volkswagen Excellence corresponds to long-term, basic, profit-performance-orientated quality politics, which aligns all employees to customers and processes.

The bases of quality politics are the cornerstones of Excellence:

- **Customer orientation**
  Demands of external and internal customers are the centre of business. Criterion for the success is the satisfaction of customers with the performance and their loyalty towards the company.
- **Result orientation**
  For Volkswagen superior high quality is the key in order to compete best and to achieve both long-term and excellent results for customers, employees, suppliers, traders and society.
- **Leadership and target consequence**
  Successful action is structurally and systematically co-ordinated for best results. Outstanding performances are reached by the strategic orientation of Volkswagen Excellence, by quality awareness and the commitment of our executives and employees.
- **Process-orientated management**
  Fast targets, guaranteed by the optimal use of resources are reached by resolute process orientation and assessment. Decisions are made on the bases of facts and strategic orientation.

[70] Konzern Qualitätssicherung, Appendix A1

- **Employee development and participation**
  Everybody influences the quality and the success of performances. Qualified and innovative employees are actively supported and encouraged to participate.
- **Continuous learning, innovation and improvement**
  All employees develop continuously through creativity and learning. The permanent process for improvement is founded on well-directed methods as well as the effective exchange of knowledge.
- **Business partnerships**
  Partnership behaviour towards suppliers, dealers and other organisations by the company needs to be excellent in order to maintain consistent business connections, which both sides benefit from.
- **Responsibility towards the public**
  Environmental and social competences cause confidence in the public. Considerate dealings with resources throughout the product life cycle increase our credibility and esteem.

Quality-Control-Circle philosophy

In order to build up a good image, the Quality-Control-Circle Philosophy was developed. This includes the principle of customer-supplier.[71] This principle is based on the consciousness that everyone is a customer and a supplier. The customer receives a high-quality product and the suppliers pass on a high-quality product. At the same time customer and supplier have a permanent exchange of information about demand and result.

Definition Quality-Control Circle:[72]

> The quality control ring (QCC) functions as a separate organization that is held responsible in order to examine the whole job that is supplied from previous fields, to record recognized defects and to make them visible to employ around them if possible correctly and to give in retrospective effect process, to improve around it.

At the same time the cause analysis is carried out or set in motion. QCC is extended over all manufacturing areas and even covers the quality parts of work organisational systems, like teamwork. QCC is used to control the process and is practised by the responsible organisation in unity. Apart from that higher control circles exist, which cover several organisational units. These report their feedback in into the small quality circles in determined ways.

Targets of QCC are:[73]

[71] See QRK-Philosophie 2004, pp 2-3 and Appendix A2, A3
[72] See QRK-Philosophie 2004, pp. 4 and Appendix A4
[73] See QRK-Philosophie 2004, pp. 5 and Appendix A5

- Strengthening all employees’ responsibilities for quality and productivity
- Feedback to the employees about success or failure of their work
- Identification of employees with their task
- Increasing the awareness of quality and costs
- Continuous optimisation of work contents in the own control circle towards zero defect
- Consequent prevention of trouble cases and accelerated causal rectification at the origin
- Increase of quality and productivity

These targets correspond to the targets of teamwork (see 4.2.5).

Tasks of QCC are (see Fig. 4.12):

- To check:
  - Control of parts or work routine o.k. /n.o.k.
  - Checking as 100%-control or spot check
- To record:
  - Recording of trouble cases
  - Analysis of control variable (for example, numbers of trouble cases)
  - Determine the difference of control variable and set point value

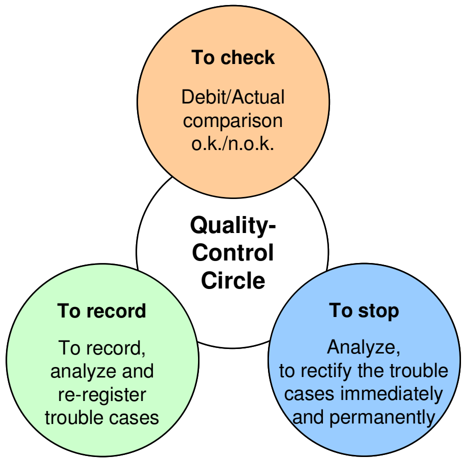

Fig. 4.12: Quality-Control Circle
Source: QRK-Philosophie, pp. 7 and Appendix A5

- To stop:
  - Immediate rectification of trouble cases on the spot
  - Analysis of reasons
  - Lasting rectification of trouble cases by long-term study

If one of these points is missing, the QCC is not longer operative. The understanding of QCC in teams is the following:[74]

- Worker self monitoring; every team member checks their own work routine and guarantees that trouble cases are rejected and recorded (by consultation with the QCC-worker, etc. or marking on the vehicle);
  20% of the parts are checked on a test basis according to constant updated main emphasis lists
- Trouble cases are entered on the so-called “handhelds” (minicomputers) on data recording systems by the QCC-worker

[74] See QRK-Philosophie 2004, pp. 8 and Appendix A5

- When dealing with trouble cases the causal agent gets immediate feedback; when main emphasis problems arise, a form of measure for prosecution has to be drawn up; constant feedback information about quality in their own QCC is announced in team discussions; when trouble cases arise in a QCC a lesson for the workers takes place; external support may be called for.

4.3 Basics of quantity

4.3.1 Hard Facts

Hard facts are composed of numbers and indexes. Indexes can be absolute figures, ratios, structure figures and relation figures. In this analysis the indexes are ratios. These ratios are relations between the production figures. The indexes have to be regarded critically because they just represent relations of numbers of a certain base. So there is not the possibility of taking a relation and comparing it to another relation with the same name, the bases of both must be the same.

An index can be seen as a calculable number that helps to qualify information to take a decision.[75]

Utilisation of indexes:[76]

- Indexes can be important planning and decision bases
- Indexes have to be handled with care, because they involve risks
- A big advantage of indexes is the optimisation of an amount of figures and therewith making them clear and expressive
- A disadvantage is the difficulty to get an optimum out of the information
- The quality of the indexes corresponding to their content of information is related to the accuracy of the information system

<u>Numbers of units</u>

The numbers of units can best be explained with the entire process of the merge of a vehicle. Marketing and manufacturing planning demand a certain amount of vehicles from the production. This amount is the scheduled number of units. The production tries to produce these cars, but problems can occur and the production has a lack of vehicles. The produced cars represent the actual number of units.

[75] See Heinen 1976, pp. 147
[76] See Gritzmann, K. (1991), pp. 44; Merkle, E. (1982), pp. 329; Schürrle, L.-H. (1996), pp. 12

<u>Times</u>

Cycle times

The cycle time is the time in which in each case a unit is finished, so that the flowing system produces the planned quantity.[77] The cycle times are divided into actual cycle time, scheduled cycle time and the so-called technical cycle time.

The actual cycle time is the average time needed for every unit to produce the actual number of units. The scheduled cycle time accordingly is the time for producing the scheduled number of units. The technical cycle time will be explained in the following. First the number of units lost by maintenance breakdowns must be determined. This number has to be added to the actual number of units, because this number of units could have been manufactured with no breakdowns. The cycle time to produce this fictitious number of units is called technical cycle time.

Manufacturing time

Manufacturing time is the set or needed time that a certain task claims for its execution.[78] When the manufacturing time is bigger than the cycle time additional workers must be deployed in this operation.

Downtime

The period of the first initiation up to the scrapping of a facility is the entire utilisation time. The entire utilisation time of a facility can be divided into actual utilisation time (uptime) and the stop-times (downtime), in which a resource is not used productively. Stop-times describe all times in which a facility carries on without enacting an operation.

Every machine has an uptime and a downtime. The downtime caused by breakdowns is called breakdown time. Breakdown time is not planned like, for example, the planned maintenance time.

To calculate the breakdown time the number of units must be determined first. The basis for this determination is the lost number of units.

$$t_{C1} = \frac{t_{SH}}{n_A + n_L} \quad \text{[Min/unit]} \qquad (3)$$

t_{C1} = theoretical cycle time [min/unit]
t_{SH} = shift time [min]
n_A = actual number of units [...]
n_L = number of lost units [...]

$$t_B = t_{C1} \cdot n_L \quad \text{[min]} \qquad (4)$$

[77] See VW Intranet
[78] See VW Intranet

t_B = breakdown time [min]
t_{C1} = theoretical cycle time [min/unit]
n_L = number of lost units […]

End-of-line repair (rework)

End-of-line repair are activities, which must be performed to avoid rejects in order to reach the high-quality state when the product is released. The registration occurs on site through the responsible inspection places using information about the error cause. Those parts and vehicles that get a certain status at a certain checkpoint, and do not have to be reworked, are called direct runners.

Effectiveness and Efficiency

Effectiveness is the fulfilment of demanded objectives with which the degree of fulfilment is measured by the conformity with the demands, whereas efficiency is the fulfilment of tasks with a minimum of resources and effort.

Overall Equipment Effectiveness[79]

The Overall Equipment Effectiveness (OEE) is a way of measuring the availability, speed and quality of equipment. The main factors that influence OEE are known as the six big losses.

OEE measure	**Loss category**	**Six big losses**
Availability	Downtime losses	1. Equipment failure (breakdowns) 2. Changeovers – setup & adjustment
Performance	Speed losses	3. Minor stoppages 4. Reduced speed
Quality	Defect losses	5. Process defects 6. Reduced yield

Fig. 4.13: The six big losses
Source: Managing resources efficiently, pg. 66

How to calculate OEE

The OEE formula calculates the separate components of availability, speed and quality so that improvement initiatives can be focused.

By calculating the availability it is possible to quantify downtime-losses caused by equipment failure or changeovers.

[79] See Managing resources efficiently, pp 60

The measure of performance is important since it shows whether there are any speed-losses caused by minor stoppages or reduced speed.

The percentage of good quality production in relation to the total production measures the proportion of defects in relation to producing defects or quality-losses. If machine capacity is used for the production of rejects, this capacity cannot be recovered and, in addition, there are rework- or scrapping-costs associated with defects.

Availability losses

Equipment availability refers to the percentage of the planned operation time that the equipment was actually available. Mathematically the formula for calculating availability is as follows:

$$A_V = \frac{t_{AO}}{t_{PO}} \cdot 100\% \quad [\%] \tag{5}$$

A_V = availability [%]
t_{AO} = actual operation time [min]
t_{PO} = planned operation time [min]

The planned operation time is calculated by taking the total working hours for a period of time (in this case for the year 2005) and subtracting any time required for planned and preventative maintenance:

$$t_{PO} = t_W - t_{PM} \quad [\text{min}] \tag{6}$$

t_{PO} = planned operation time [min]
t_W = working hours [min]
t_{PM} = planned maintenance time [min]

The actual operation time is the actual time the equipment is available for production. It therefore excludes downtime caused by breakdown and changeovers.

$$t_{AO} = t_{PO} - t_B - t_{CH} \quad [\text{min}] \tag{7}$$

t_{AO} = actual operation time [min]
t_{PO} = planned operation time [min]
t_B = breakdown time [min]
t_{CH} = changeover time [min]

Speed Losses

Speed losses are caused by equipment not operating at full speed. The speed loss percentage is calculated by dividing the actual rate of production by the theoretical rate of production. The speed ratio shows the percentage of machine capacity that is lost as a result of minor stoppages and reduced speed or idling.

$$S_R = \frac{n_A}{n_P} \cdot 100\% \quad [\%] \tag{8}$$

S_R = speed ratio [%]

n_A = actual number of units […]
n_P = Planned number of units […]

Defect losses

Quality losses are the result of using machine capacity to produce defective products. The quality ratio is calculated by dividing good quality production by total production (including rejects).

$$Q_R = \frac{n_G}{n_A} \cdot 100\% \quad [\%] \tag{9}$$

Q_R = quality ratio [%]
n_G = number of units good quality […]
n_A = actual number of units […]

Calculation of OEE

The OEE is calculated by multiplying the three losses.

$$OEE = A_V \cdot S_R \cdot Q_R \quad [\%] \tag{10}$$

OEE = overall equipment effectiveness [%]
A_V = availability […]
S_R = speed ratio […]
Q_R = quality ratio […]

The six big losses

It is useful to relate what is known as the six big losses to availability, speed and quality and hence Overall Equipment Effectiveness. The table below summarises the big six equipment losses and how these relate to availability, speed and quality.
The six big losses measure the cause of deterioration in the separate components.

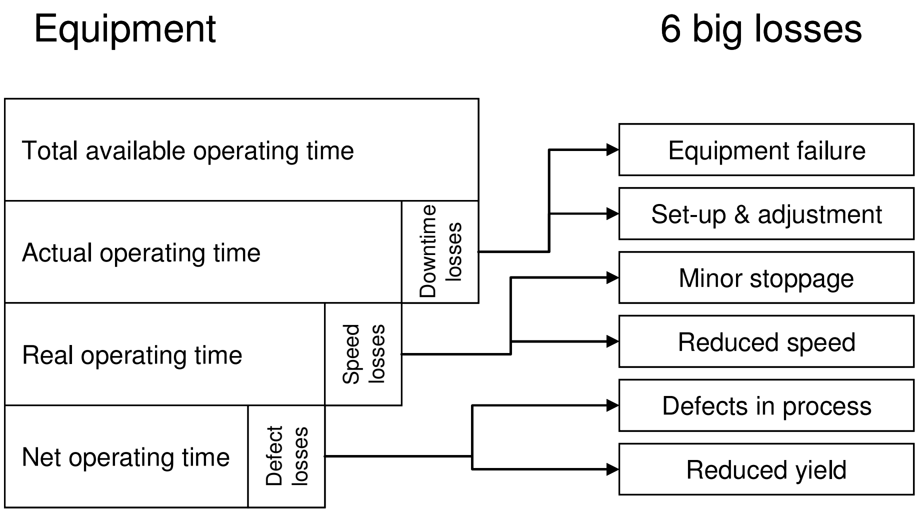

Fig. 4.14: The six big losses in equipment operation
Source: Managing resources efficiently, pp. 66

<u>Productivity</u>

The indexes of productivity represent the ratios of input and output. The input stands for the production factors and the output means the performance of work. In this case the vehicles every worker has manufactured on average and the vehicles every worker has manufactured per hour measure the productivity. These indexes come close together but the index vehicles per worker's hour includes the shift model additionally. So not just the workers and the vehicles are examined but the net working time of each shift and the number of shifts are contained in the calculation.[80]

Indexes of productivity are just comparable if they have the same bases. That means that the period of time must be the same for the compared figures.

4.3.2 Soft Facts

Flexibility

Definition: "Flexibility can be defined as the adaptability of a system onto the changes with the products to be produced, the production demands as well as the production conditions."[81]

The increase of individual customer wishes demands an enhancement of the variety of versions of single products. As a result of this, high-volume production will have to change to a volume production or even small-volume production.

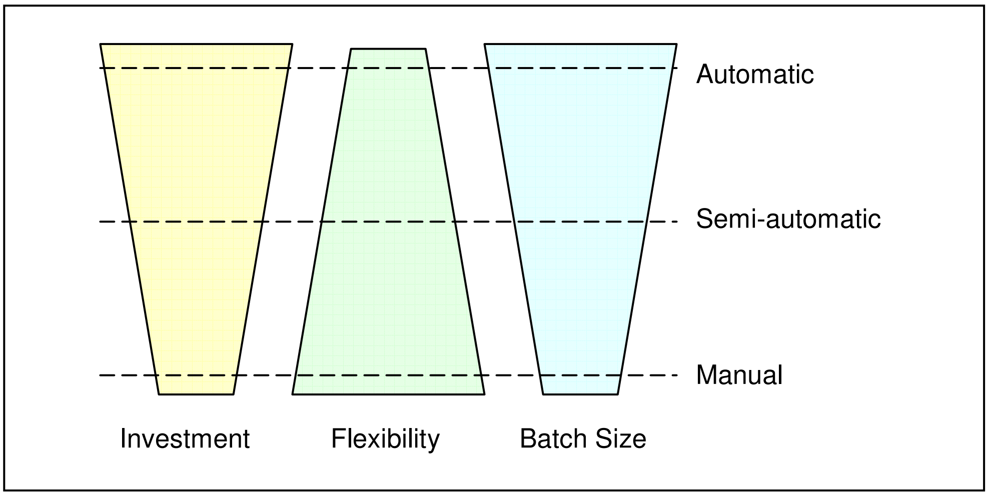

Fig. 4.15: Flexibility
Source: Lotter 1998, pg. 3

The criteria of selections for different assembly techniques are shown in the figure before. One of the prerequisites for automation is a high number of units. Furthermore, a highly automated assembly means high investment costs and a limited flexibility. Manual assembly, on the other hand, stands for a highly flexible assembly with low investment costs. A further advantage of manual assembly is the possibility of

[80] See VW Intranet
[81] See Fichtmüller 1996, pp. 8

reacting very quickly to changing customer wishes and market demands. But, the manual production is less suitable for big numbers of units.

A good compromise between both, automatic and manual assembly is the so-called hybrid-system, a semi-automatic assembly with automatic stations and manual workstations combined. These hybrid-systems are getting bigger and bigger in the car-making industries, because of shorter product life cycles and increasing variations.

Complexity[82]

The entirety of all properties of a state or object in the sense of versatility is meant by complexity. Complexity costs are assessed factors of consumption, which are justified by company-conceptions in all fields (research & development, marketing, production, procurement, organisation) in the versatility. The control of the complexity of development, production and logistics processes is regarded as a key for the preservation of the competitive capacity.

Versions on one line

The bigger the variety of versions on one line is, the more difficult and more complicated the entire working process is.

Variety of versions[83]

The variety in the production and marketing processes leads to massive complexity problems. The variety is controllable through generalisation, concentration on organisation and information, flexible workstations with complete processing and flexible automation.

Diverse causes

Adaptations to market needs and continuous technological changes necessitate continuous modifications in the product structure that lead to unclear complexity automatically. Increased numbers have a direct influence on the production costs of a product. As a consequence, a company strives for mass production while the market is demanding individual products and therein a big variety of versions.

Manufacturer disadvantages increased because of variety

Every variant is combined with additional expenditure. This expenditure can be put down only onto few final products. That must increase the sale price significantly,

[82] See VW Intranet
[83] See VW Intranet

and in this way the competitive capacity sinks, too. The information and communication expenditure increases with the increased complexity and thus strong information structures are necessary. Hence, time becomes a factor of competition. The changing process has a greater influence on the production costs than the manufacturing process because of increased variant numbers.

5. Examinations and results of costs, quality and quantity

The production of a vehicle is divided into the following parts: press shop, body shop, paint shop and final assembly. Furthermore, the components are produced in parallel lines. In the press shop, the sheet metal is pressed out of coils. These metal plates are then welded together in the body shop. In the paint shop, the body is painted. The last part of the vehicle production is the final assembly where the components and parts are mounted onto the body. This part of the production will be analysed in detail.

In Wolfsburg, the Golf A5 is produced in two parallel assembly lines which are the most highly automated lines of the three locations analysed. These assembly lines, which are in Hall 54 in Wolfsburg, are already well known as the most automated vehicle assembly lines worldwide. Apart from the Golf A5, the Golf Plus is also assembled on one of these lines. In this thesis only the Golf A5 line will be analysed. Each line is divided into highly automated parts, which are called Mechanisation 1, 2 and 3, and manual parts, which are positioned between each of the three Mechanisation sections. So, the level of automation changes several times within the whole line from high automation to low automation. Because of this, buffers are necessary when the level of automation jumps to another level. In this thesis, only the three Mechanisation sections are analysed. Each Mechanisation section consists of the manufacturing of components and the mounting of those components onto the body. Furthermore, only those stations are analysed which are located on the second floor and where the components are mounted onto the body. As not all the stations are analysed, the writer has specified them as Assembly Parts 1, 2 and 3.

The assembly line begins with Mechanisation 1 where the doors are removed from the body and produced on a separated, parallel production line. The completed doors are then integrated in the main assembly line after Mechanisation 3. The removal of the doors is not analysed. Mechanisation 1 mainly includes the following operations:

- **Roll forming of the tailgate and doors**: Pressing the sealings on the body.
- **Fitting the cockpit location brackets**: Screwing location brackets into the body. Later on, the cockpit is screwed into the brackets.
- **Cleaning and priming window flanges**: First, the window flanges have to be cleaned with a special cleansing agent. After that a special fluid that enables a chemical reaction between glass and body and not between glass and gloss paint is applied.

- **The fitting of the complete cockpit**: The full cockpit is delivered to the line, glued with cockpit glue and then put into the body and screwed as one component. After fitting the cockpit, the cable boxes, which prevent the cables dangling, have to be put away during the cockpit fitment.

All these operations belong to Assembly Part 1. Mechanisation 2 mainly includes the following operations:

- **Stamping VINs**[1]: Three VINs are stamped into three positions on the body.
- **Lifting up and fitting complete power train into the body**: A lifter transports the whole power train from the bottom upwards into the body. After that, all underbody work has to be done. This includes the screwing of fuel tank, rear axle, engine-gearbox bearer, suspension strut and exhaust system.
- **Fitting gearshift**: The gearshift is screwed from above.
- **Fitting all windows**: The windows are taken, glued and put onto the flanges of the body.

These operations belong to Assembly Part 2. Mechanisation 3 mainly includes the following operations:

- **Fitting the CW trim panels**[2]: 2 panels are screwed under the vehicle.
- **Putting in and fitting the battery**: The battery is put and screwed into the body.
- **Fitting the cross member**: The cross member is screwed into the body.
- **Fitting the rear bumper**: The rear bumper is put and screwed into the vehicle.
- **Fitting the complete front-end**: The full front-end is delivered to the line and screwed into the vehicle as one component.
- **Placing the spare wheel in the boot**: The spare wheel is put into the boot.
- **Fitting all the wheels**: The wheels are delivered to the line and screwed into the vehicle.

These operations take place in Assembly Part 3.

The production of the Auto5000 GmbH has, except for a few stations, the same structure as the production of the Golf A5. But the stations with the examined operations are not in the same order and the whole assembly has a lower degree of automation. There are more manual stations in the assembly line, which means that more workers are necessary to produce the vehicles. And, due to the lower degree of automation, there are no big jumps between high and low automation as in the Golf A5 assembly

[1] VIN = Vehicle Identification Number
[2] CW = Constante Widerstand (drag coefficient)

line of Wolfsburg, which means there are not that many buffers. The entire assembly line of the Auto5000 GmbH looks more homogeneous.

The production of the Golf A5 in Uitenhage has an even lower automation degree. There, the stations are also not placed in the same order as in the Golf A5 assembly line in Wolfsburg. In Uitenhage, even more workers are necessary to produce the vehicles.

Before starting the analyses of costs, quality and quantity the same basis for the examined area has to be guaranteed for all production sites. Starting points are the 3 Assembly Parts of the assembly line in Wolfsburg. They are a point of reference for both of the other productions sites. All equivalent stations are compared with the stations of Assembly Parts 1, 2 and 3. As the order of the stations in the Auto5000 GmbH and Uitenhage are different with respect to the order of Assembly Parts 1, 2 and 3, the relevant stations of the assembly lines are picked out and put in the order of the Assembly Parts. This procedure is necessary for creating different levels of automation. By examining the 3 different assembly lines, up to 3 different possible ways to assemble a certain component can be differentiated. The possible ways are presented in detail in a morphological box. This is the basis for creating different levels of automation in a matrix. The 3 morphological boxes for the 3 Assembly Parts are shown in **Appendix B1-B3**. There you can also see how the assembly proceeds in every production site.

The morphological boxes are the basis for creating different levels of automation, which are listed in matrixes. For each Assembly Part different levels of automation will be created. Therefore, each Assembly Part gets its own matrix.

The matrixes for the three Assembly Parts are presented in **Appendix C1-C3**. For a better understanding, it is advisable to take a closer look at the matrixes while reading the following paragraphs.

On top each matrix shows the relevant stations of each Assembly Part, which are coloured in grey as shown in Fig. 5.1 There, each column stands for one station.

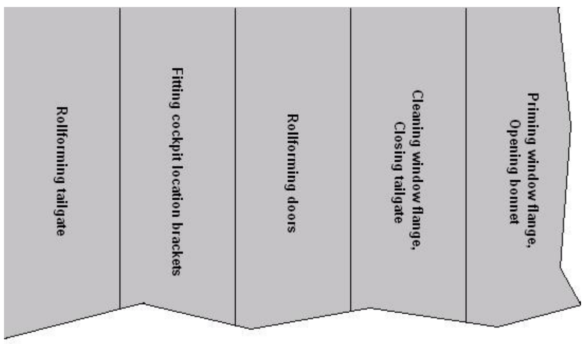

Fig. 5.1 Example for relevant stations
Source: Own presentation

In each line the different levels of automation are shown as in Fig. 5.2 on the following page. The starting point of creating different levels of automation is the way, in which the Golf A5 is assembled in Wolfsburg. Therefore, the first level of automation represents the way in which the Golf A5 is assembled in Wolfsburg. With the growing number of levels from top to bottom, the level of automation decreases. For each further level the most meaningful stations regarding costs are deautomated. The last level of automation always represents the way in which the Golf A5 is assembled in Uitenhage. This level shows the least automated way of assembling. In between, there is one level of automation that shows how the Touran in the Auto5000 GmbH is assembled. Depending on the stations the 3 matrixes of Assembly Parts 1, 2 and 3 have different numbers of levels of automation (5, 5, 7 levels). In each field of the matrix the following information for a certain station at a certain level of automation is shown:

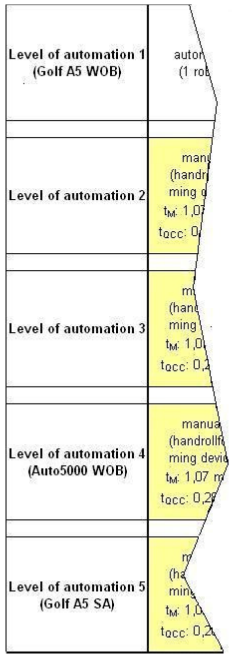

Fig. 5.2 Example for levels of automation
Source: Own presentation

- **Way of assembling (automated or manual)**: Manual means that workers are involved in the mounting process. These fields are yellow marked. In automated stations, assembly does not involve workers, except for depositors, who are also mentioned in relevant stations, and the operators of machines. These fields are coloured white.
- **Number and kind of machines**
- **Manufacturing time t_M** (only in manual stations): The manufacturing time t_M is the time that is necessary to fulfil all operations with 1 worker in one station with a certain number and different kinds of machines.
- **QCC time t_{QCC}** (only in manual stations): The QCC time t_{QCC} describes the time a QCC worker needs to check the operations of a certain station.

In the whole process, the number of workers that are necessary in a certain station is calculated with the help of the manufacturing time t_M and the cycle time t_C (see Formula 12). So, for each manual station the number of workers can be calculated. For automated stations the assembly guidelines are only presented as rough instructions. Manufacturing times are not available. When changing the automated stations into manual ones, the manufacturing times can be obtained from the working schedules of the Golf A4 assembly, where most of the stations are manual, and, if necessary, from the Golf A5 assembly line in Uitenhage. Furthermore, manufacturing times can be obtained from those analyses that have already been done in the company. In the Auto5000 GmbH no times are taken down.

As already mentioned, quality costs in the form of appraisal costs are considered in this work. On the one hand, the automated operations have to be checked and, if necessary, reworked. These kinds of appraisal costs are considered in the Reworking phase. In practice, the reworking station only exists at the production site of the Golf A5 in Wolfsburg and it is the last station of each Mechanisation where all operations are checked. But, in order to represent the reworking measure in the automated stations of the other levels of automation as well the manufacturing time of rework in the first level of automation has to be cut down to the other levels of automation, depending on the number of stations that are automated at that certain level. Therefore, all levels, which have no automated stations, have no reworking either. How the other manufacturing times of reworking are exactly calculated is explained in **Appendix C4-C8**. On the other hand, all the manual stations have to be checked by the QCC workers, which means that in each manual field the QCC time t_{QCC} is given, which is calculated on the basis of the Auto5000 GmbH. How the QCC times are exactly calculated in each station is described in **Appendix C4-C8** as well. In the matrixes the total times are given in the green columns (see in Fig. 5.3).

The blue columns at the right side of each matrix (see Fig. 5.3) show several total times that are necessary for the analysis. Added up are the manufacturing times t_M of all manual stations. Furthermore, some additional personnel (mostly operators for the machines) are necessary in automated stations. Their manufacturing times are only known for the first level of automation. To take into consideration the factor of human resources in the other levels of automation as well, the manufacturing time is broken down as it has been done for the reworking measure. If there are no automated stations at a certain level of automation, no other workers exist. The manufacturing time for those comes to 0 min.

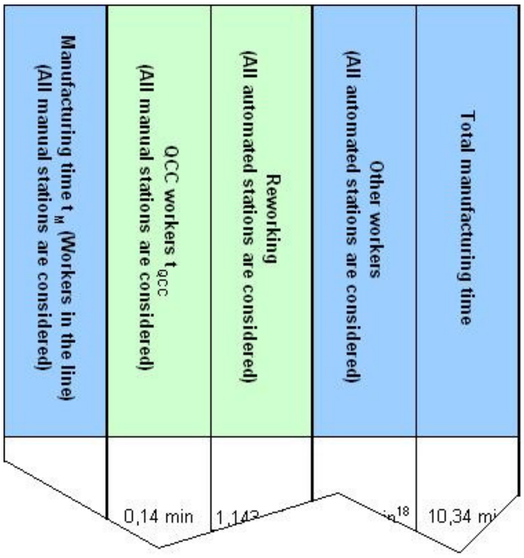

Fig. 5.3 Total times
Source: Own presentation

Apart from other workers, some automated stations require depositors that put certain parts into the operating material. Their manufacturing times are added up in the column for depositors (not shown in Fig. 5.3). The last column shows the total manufacturing time of all personnel involved. By dividing this time with the cycle time t_C the total number of personnel can be determined.

manual (3 manipulators t_M: 2,3 min) t_{QCC}: 0,14 min	automatic (18 facilities, 1 robot and 1 lifter)	manual (accu screwdriver t_M: 1,2 min[5]) t_{QCC}: 0,14 min[6]

Fig. 5.4 Example for bold bars
Source: Own presentation

Between some successive stations there are bold bars (see Fig. 5.4), which indicate that these stations cannot be put on top of each other if a certain level of automation is put into practice. Either these transitions have to be decoupled by buffers or the stations have to be put in a different sequence. The levels of automation without bold bars are already in the correct order for putting into practice.

Each of the three matrixes have several annotations that describe how the times are determined. These annotations are also explained in **Appendix C4-C8**.

Now the necessary preparations are finished and therewith the basis is created for carrying out the examinations of the three areas costs, quality and quantity.

5.1 Examinations and results of costs

The analysis of costs has to take into consideration all the relevant costs. In this respect the consideration of earnings is not necessary because whatever the level of automation is, it has no influence on earnings and above all it is not possible to determine the earnings for the examined part of the assembly line. Because of this, the analysis is a pure comparison of costs. It makes use of the methods of cost and investment calculation and the cost comparison calculation method in particular, which is explained in Ch. 4.1.4.

The first step is to choose the cost calculating system as the basis for further considerations. The second step is to identify the relevant costs. All those costs that are not influenced by a change of the level of automation are not taken into consideration in the calculation. The optimal level of automation has the lowest total cost per unit.

By comparing cost analysis, the principle of the relevant costs and the cost structure is described by the partial cost calculation as the cost calculating system. For middle- and long-term considerations the full cost calculation may be recommended. But in this case, it is futile because of the inadequate influence and recording. Inadequate influence here means that costs can be ignored if they do not change with the level of automation. Inadequate recording means that certain costs are relevant but they only have a small impact so that they can be ignored as well. Examples for an inadequate recording are employee representative committees, parking for employees, canteens, facilities, and medical service centres of the plant.

The identification of costs have been done with the resource attempt as cost-type accounting.[3] The costs per unit are calculated by dividing the total costs per year with the number of units per year. The relevant costs are described in detail in the following chapter. A statement about the presented cost types is made in Ch. 4.1.3.

[3] See Ch. 4.1.3

5.1.1 Relevant cost types

Basically, costs for operating material stand in contrast to personnel costs. With an increasing level of automation the investment costs for operating material grow whereas personnel costs decrease.[4] But apart from that, all those costs that influence the decision of the optimal level of automation have to be taken into consideration. The following table shows the different cost types classified according to resources as explained in Ch. 4.1.3. Besides, the resource type Personnel is subdivided into direct workers and maintenance, which will be explained in detail later on.

Distribution of costs		
1. Personnel	Direct workers	Worker in the line
		Operator
		QCC-Worker
		Reworker
		Depositor
	Master	
	Maintenance	Electrician
		Technician
		Fitter
		Technical Service
	Planning	
	Industrial Engineering	
	Quality Assurance	
	Controlling	
	Logistics	
2. Operating material	Capital investment	
	Energy costs	
	Equipment for maintenance use, facilities wear parts	
	Planning costs for external companies	
3. Material	Raw material	
	Auxiliary material	
	Operating supplies	
	Capital freeze	
4. Space	Buildings and surface	
5. Information	Hard- and software	
6. Additional costs	Quality costs	
	Standstill costs	

Tab. 5.1 Distribution of costs
Source: Own presentation

In the analysis, only the employees who are relevant can be seen in connection with the Assembly Parts. For this, the prevailing number of personnel and the personnel costs per year of every selection of personnel is necessary. Only indirect employees who work very close to the line are included because there is a better overall view and almost no change in the assignment of personnel in case the level of automation is changed. Employees above the master in hierarchy are not taken into account. In the Auto5000 GmbH workers are called talents and the master is called the operation engineer.

Usually, 1 master is put in charge of about 15 workers; a ratio that will be the basis for this analysis. To calculate the gross personnel, a bonus has to be added to the net personnel in three shifts. This bonus depends on the production site and describes the absentee proportion. It considers illness, holidays and training courses.

At this place the costs per unit of direct workers will be differentiated. Direct workers are subdivided into workers on the line for manual operations, operators that

[4] See Chap. 4.1.1

supervise the machines, QCC workers and reworkers for quality control as well as depositors who dispose parts in fully automated facilities. For the calculation the number of units n is essential:

$$n = \frac{t_{SH} \cdot n_S \cdot d_W}{t_C} \quad \text{[units]} \tag{11}$$

n = number of units [units]
t_{SH} = shift time [min]
n_S = number of shifts […]
d_W = working days […]
t_C = cycle time [min/unit]

To get the number of workers that are needed to carry out a certain operation, the manufacturing time $t_{M\_...j}$, which describes the time that is necessary to carry out this operation with 1 worker, is divided by the cycle time t_C:

$$n_W = \frac{t_{M\_...j}}{t_C} \quad [\ldots] \tag{12}$$

n_W = number of workers […]
$t_{M\_...j}$ = manufacturing time of station j for the prevailing worker [min/unit]
t_C = cycle time [min/unit]

The personnel costs for the given station can be determined by multiplying this number of workers with the personnel cost rate for the prevailing worker. But, if the assembly is carried out in several shifts the personnel cost rate has to be multiplied with the number of shifts:

$$C_{P\_...j} = n_W \cdot n_S \cdot C_{P\_...} \quad [€] \tag{13}$$

$C_{P\_...j}$ = personnel costs for station j for the prevailing worker [€]
n_W = number of workers […]
n_S = number of shifts […]
$C_{P\_...}$ = personnel cost rate for the prevailing worker [€]

The costs per unit can be calculated with the following formula:

$$c_{P\_...j} = \frac{C_{P\_...j}}{n} = n_W \cdot n_S \cdot C_{P\_...} \cdot \frac{t_C}{t_{SH} \cdot n_S \cdot d_W} = \frac{t_{M\_...j}}{t_C} \cdot n_S \cdot C_{P\_...} \cdot \frac{t_C}{t_{SH} \cdot n_S \cdot d_W}$$

$$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_...}}{t_{SH} \cdot d_W} \quad [€/\text{unit}] \tag{14}$$

$c_{P\_...j}$ = costs per unit for station j for the prevailing worker [€/unit]
$t_{M\_...j}$ = manufacturing time of station j for the prevailing worker [min/unit]
$C_{P\_...}$ = personnel cost rate for the prevailing worker [€]
t_{SH} = shift time [min]
d_W = working days […]

These costs are variable costs. They do not change with the capacity utilisation or with the number of units n. The number of units n can change by changing the cycle time t_C, the shift time t_{SH}, the number of shifts n_S or the working days d_W. As can be seen, Formula 14 does not depend on the cycle time t_C or on the number of shifts n_S. The only possibility of changing the costs per unit $c_{P\_...j}$ with the number of units n is by changing the shift time t_{SH} or the working days d_W. But, both of these parameters are directly connected with the given personnel cost rates $C_{P\_...}$. This is estimated for a certain shift time t_{SH} and for certain working days d_W, otherwise workers will work longer without pay compensation.

To lower the costs it is possible to lower the manufacturing time $t_{M\_...j}$. If the assembly process is already optimised, it is also possible to reduce the personnel cost rates. But this is almost inconceivable, especially in Germany.[5]

For determining the personnel costs for the masters, first, the number of necessary masters is to be calculated. As already mentioned, 1 master is planned for about 15 workers:

$$n_{Mj} = \frac{t_{M\_DWj} + t_{M\_QCCj} + t_{M\_RWj} + t_{M\_OWj} + t_{M\_Dj}}{15 \cdot t_C} \quad [\ldots] \qquad (15)$$

n_{Mj} = number of masters for station j […]
t_{M_DWj} = manufacturing time worker in the line of station j [min/unit]
t_{M_QCCj} = manufacturing time QCC-worker of station j [min/unit]
t_{M_QRWj} = manufacturing time reworker of station j [min/unit]
t_{M_OWj} = manufacturing time other worker of station j [min/unit]
t_{M_Dj} = manufacturing time depositor of station j [min/unit]
t_C = cycle time [min/unit]

The personnel costs per unit for the master are calculated with the following formula:

$$c_{P\_Mj} = \frac{C_{P\_Mj}}{n} = n_{Mj} \cdot n_S \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot n_S \cdot d_W} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W} \quad [€/\text{unit}] \qquad (16)$$

c_{P_Mj} = costs per unit for station j for the master [€/unit]
C_{P_Mj} = personnel costs for station j for the master [€]
n = number of units [units]
n_{Mj} = number of masters for station j […]
n_S = number of shifts […]
C_{P_M} = personnel cost rate for master [€]
t_C = cycle time [min/unit]
t_{SH} = shift time [min]
d_W = working days […]

By putting Formula 15 into Formula 16, it can be seen that the cycle time t_C can be reduced. Thus, the personnel costs for the master per unit are variable costs per unit that do not change with the capacity utilisation:

$$c_{P\_Mj} = n_{Mj} \cdot \frac{C_{P\_M}}{n} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W} = \frac{t_{M\_DWj} + t_{M\_QCCj} + t_{M\_RWj} + t_{M\_OWj} + t_{M\_Dj}}{15 \cdot t_C} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$$

In the maintenance section all operating materials have to be serviced regularly and, if necessary, repaired. Maintenance personnel are subdivided into electricians, technicians and fitters. Furthermore, workers for the technical service have to be considered. As well as the other maintenance personnel, the number of workers increases with the level of automation in the assembly line. For the calculation of the costs, only such maintenance that is caused in the analysed processes is relevant. In this respect internal and external personnel have to be considered. With increasing

[5] See Fichtmüller 1996, pp. 45 and Ch. 4.1.1

automation more specialised knowledge becomes important. In practice it is very difficult to assign maintenance costs to every single station correctly because maintenance personnel are mostly used for a certain area of the whole assembly. Therefore, a roughly estimated percentage rate has to be fixed and this percentage rate is taken from the investment costs because usually more complex machines have more complex components that are more expensive. The percentage rate is about 50% for all the personnel costs of maintenance, including the workers from the technical service:[6]

$$c_{P\_MAj} = c_{INVj} \cdot 0{,}5 \quad [€/unit] \qquad (17)$$

c_{P_MAj} = maintenance costs per unit for station j [€/unit]
c_{INVj} = investment costs per unit for station j [€/unit]

The maintenance costs per unit c_{P_MAj} are fixed costs that decrease when running to capacity. The reason for this is that the investment costs per unit c_{INVj} are fixed costs too, because they are calculated by dividing the investment costs per year and the number of units per year. The formula for calculating the investment costs per unit c_{INVj} is mentioned below.

It is difficult to determine the personnel costs for the planning of the line. The more automated the assembly line is, the higher the expenditure to plan the line. In the Volkswagen AG, an estimated percentage rate for planning personnel is 7% of the investment costs or the yearly depreciations:[7]

$$c_{P\_Pj} = c_{INVj} \cdot 0{,}07 \quad [€/unit] \qquad (18)$$

c_{P_Pj} = planning costs per unit for station j [€/unit]
c_{INVj} = investment costs per unit for station j [€/unit]

These costs are fixed costs, too.

Personnel costs for industrial engineering grow with decreasing automation because more people have to be clocked in cycle. Roughly, an employee in industrial engineering needs 1 week to clock in a 2-minute cycle of manufacturing time. These costs incur only once a lifetime, similar to investment costs. The following formula on the next page shows the costs per unit for an industrial engineer employee:

Number of weeks for clocking in cycle

Total costs per week for clocking in cycle

Convert total costs into costs per unit

$$c_{P\_IEj} = \frac{\sum t_{Mj}}{2\,min/unit} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n} \quad [€/unit] \qquad (19)$$

c_{P_IEj} = industrial engineering costs per unit for station j [€/unit]
$t_{M\_...j}$ = manufacturing time of station j for the prevailing worker [min/unit]

[6] Details from Volkswagen AG Wolfsburg, department Planning
[7] Details from Volkswagen AG Wolfsburg, department Company Planning

d_{WW} = working days per week […]
C_{P_IE} = personnel cost rate for Industrial Engineering employee [€]
d_W = working days […]
a = period of depreciation […]
n = number of units [units]

Personnel costs for industrial engineering are fixed costs that decrease when running to capacity.

Personnel for quality assurance are not relevant for the analysis because with changing levels of automation these personnel will not change. But, reworkers and QCC workers on the assembly line are already considered as direct workers. For controlling personnel, the same assumption for quality assurance can be assumed. These personnel are also not taken into account.

Personnel for logistics are also not taken into consideration. By proceeding on the assumption that material has to be brought to the assembly line it is not important how to transport it to the line, because the personnel for logistics do not change with the level of automation. But, with increasing automation the expenditure for logistics will increase, because some material has to be transported in special boxes, which causes additional personnel. Therefore, a small increase with higher automation can be expected, but is not considered in this thesis.

Costs for investment take the most part of the second resource. This includes the purchase, building up and opening of machines and facilities. Investments in handling systems, which means conveyor belts with control engineering and hanger facilities, as well as material flow engineering, are not taken into consideration, because they would be necessary for the implementation of other assembly concepts too. Hence, it can be assumed that handling systems do not depend on the level of automation. The exceptions to be considered here are the lifters for lifting up the power train into the body as well as those facilities that place components and parts so that robots can reach them. These complex facilities are not needed on manual lines where workers can reach components and parts by hand. The costs for these special facilities are already included in the investment costs of the given stations. The period of depreciation is usually 7 years. A linear depreciation is assumed. To calculate the investment costs per unit of each station, the investment costs have to be divided by the period of depreciation and the number of units:

$$c_{INVj} = \frac{C_{INVj}}{a \cdot n} \quad [€/\text{unit}] \qquad (20)$$

c_{INVj} = investment costs per unit for station j [€/unit]
C_{INVj} = total investment costs for station j [€]
a = period of depreciation […]
n = number of units [units]

The investment costs per unit c_{INVj} are fixed costs per unit because of the dependence on number of units n.

Energy costs relate to the electricity to run the machines on the assembly line. Costs for heating and lighting the hall are not considered because they will not change with the level of automation. Generally, energy costs are divided into costs for demand power that the power station has to provide and the costs for using the machines work depending on the time they are used. For both of these calculations, energy cost rates are necessary. These costs are different at certain locations. The power P_{Ej} of a given station j is necessary to calculate the energy costs per unit for this certain station as well:

$$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_...} + P_{Ej} \cdot d_W \cdot n_S \cdot \frac{t_{SH}}{60\,min/h} \cdot C_{W\_...}}{n}$$

$$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_...}}{n} + \frac{P_{Ej} \cdot d_W \cdot n_S \cdot \frac{t_{SH}}{60\,min/h} \cdot C_{W\_...}}{n} = \frac{P_{Ej} \cdot C_{POW\_...}}{n} + \frac{P_{Ej} \cdot d_W \cdot n_S \cdot \frac{t_{SH}}{60\,min/h} \cdot C_{W\_...} \cdot t_C}{d_W \cdot n_S \cdot t_{SH}}$$

Costs for demand (power)

Costs for using the machines (work)

$$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_...}}{n} + \frac{P_{Ej} \cdot C_{W\_...} \cdot t_C}{60\,min/h} \quad [€/unit] \tag{21}$$

c_{Ej} = energy costs per unit for station j [€/unit]
P_{Ej} = power for station j [kW]
$C_{POW\_...}$ = energy cost rate for power for the prevailing location [€/kW]
n = number of units [units]
$C_{W\_...}$= energy cost rate for work for the prevailing location [€]
t_C = cycle time [min/unit]
t_{SH} = shift time [min]
d_W = working days […]
n_S = number of shifts […]

This formula is only valid on the assumption that the machines run the whole working time, which is calculated by multiplying the working days d_W, the number of shifts n_S and the shift time t_{SH}. Generally, energy costs are fixed costs per unit. But, if the number of units n is not changed by the cycle time t_C but by the number of shifts n_S the second summand of Formula 21 does not change. In this case, this summand describes the variable costs per unit. The same situation would occur by changing the working days d_W or the shift time t_{SH} , but, as already mentioned, they are not allowed to change because of the dependence on personnel cost rates.

Costs for the maintenance of equipment and facility wear parts also belong to the second resource. The maintenance department has a budget for the whole area of maintenance, but yearly costs cannot be assigned to single stations. Therefore, costs for the examined area have to be assessed from the budget. Then, costs for each station are an applied percentage according to investment costs of each station. This is because of the assumption that more expensive operating materials contain more expensive components.

For both assembly lines of the Golf A5 in Wolfsburg, about 780,000 € are spent on the examined area. That means about 390,000 € are relevant for all those stations that are examined in this analysis. To calculate the equipment costs per unit, the total investment costs of the certain station C_{INVj} are divided by the sum of all investment costs of all Assembly Parts C_{INV_WOB} and multiplied with the total equipment costs C_{EQ_WOB}. So, the equipment costs are an applied percentage. To get costs per unit, the term is to be divided with the number of units n. So, the costs are fixed costs:

$$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB} \quad [€/unit] \tag{22}$$

c_{EQj} = equipment costs per unit for station j [€/unit]
C_{INVj} = total investment for station j [€]
C_{INV_WOB} = total investment costs for all Assembly Parts for Golf A5 Wolfsburg [€]
C_{EQ_WOB} = total equipment costs for all Assembly Parts for Golf A5 Wolfsburg [€]
n = number of units [units]

In the Auto 5000 GmbH about 170,000 € per year are spent on the equipment in the examined stations.[8] The calculation of equipment costs per unit is identical to the calculation of the Golf A5 in Wolfsburg:

$$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000} \quad [€/unit] \tag{23}$$

c_{EQj} = equipment costs per unit for station j [€/unit]
C_{INVj} = total investment for station j [€]
$C_{INV\_Auto5000}$ = total investment costs for all Assembly Parts for Auto5000 Wolfsburg [€]
$C_{EQ\_Auto5000}$ = total equipment costs for all Assembly Parts for Auto5000 Wolfsburg [€]
n = number of units [units]

In the plant in Uitenhageabout 146,000 € per year for the relevant stations are necessary for equipment.[9] The calculation of equipment costs per unit is the same as the calculation of the Golf A5 in Wolfsburg:

$$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_SA}} \cdot C_{EQ\_SA} \quad [€/unit] \tag{24}$$

c_{EQj} = equipment costs per unit for station j [€/unit]
C_{INVj} = total investment for station j [€]
C_{INV_SA} = total investment costs for all Assembly Parts for Golf A5 Uitenhage [€]
C_{EQ_SA} = total equipment costs for all Assembly Parts for Golf A5 Uitenhage [€]
n = number of units [units]

Planning costs for external companies are not relevant. These costs rise only if the planning of facilities is not internal but accepted from external companies.

[8] Details from Auto5000 GmbH Wolfsburg, „Lernstatt“
[9] Details from Volkswagen AG Uitenhage, department Maintenance

In the third resource, only material costs that are influenced by changing the level of automation are relevant. Hence, all raw materials for vehicles as well as all auxiliary materials are not relevant, because there are no special vehicle materials that are needed for the automated assembly. Thus, only operating supplies are relevant.[10] The only decisive part of operating supplies is the electrical power for producing compressed air. All the other supplies can be ignored because they are too small. The energy costs for the necessary power to produce compressed air in each station are calculated similarly to Formula 21:

$$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_...}}{n} + \frac{P_{OSj} \cdot C_{W\_...} \cdot t_C}{60\,\mathrm{min/h}} \quad [€/unit] \qquad (25)$$

c_{OSj} = energy costs per unit to produce compressed air for station j [€/unit]
P_{OSj} = power to produce compressed air for station j [kW]
$C_{POW\_...}$ = energy cost rate for power for the prevailing location [€/kW]
n = number of units [units]
$C_{W\_...}$ = energy cost rate for work for the prevailing location [€/kWh]
t_C = cycle time [min/unit]

Capital freeze is relevant for quantity. Because of the flexible design of the line, buffers are necessary before and behind each Mechanisation. These cause frozen capital. Costs caused by capital freeze will be mentioned in Ch. 7.

All costs for buildings and areas are not considered because it can be roughly assumed that the necessary area for the assembly lines stays constant even if the levels of automation change. Therefore, the fourth resource is not important for the analysis.

The fifth resource is also not considered because costs for hardware and software are already included in the third resource relating to investment costs.

The last resource includes standstill costs, which are missed contribution margins because the customer does not buy the vehicle if it is not produced on time and, on the other hand, quality costs (failure costs)[11]. Costs for standstill are mentioned in Ch. 7. Failure costs include the personnel for rework and in the QCC workers because most of the failures, which happen in the given stations, are remedied on the line. The small part of those failures, which occur in the considered stations and have to be remedied in the finishing operation after Mechanization 3, will be ignored.

[10] Details from Volkswagen AG Wolfsburg and Uitenhage, departments Maintenance
[11] See Ch. 4.1.3

Distribution of costs			Note
1. Personnel	Direct workers	Worker in the line	
		Operator	
		QCC-Worker	
		Reworker	
		Depositor	
	Master		
	Maintenance	Electrician	
		Technician	
		Fitter	
		Technical Service	
	Planning		
	Industrial Engineering		
	~~Quality Assurance~~		
	~~Controlling~~		
	~~Logistics~~		
2. Operating material	Capital investment		
	Energy costs		
	Equipment for maintenance use, facilities wear parts		
	~~Planning costs for external companies~~		
3. Material	~~Raw material~~		
	~~Auxiliary material~~		
	Operating supplies		
	Capital freeze		considered in Chap. 7
4. Space	~~Buildings and surface~~		
5. Information	Hard- and software		included in capital investment
6. Additional costs	~~Quality costs~~		
	Standstill costs		considered in Chap. 7

Tab. 5.2 Distribution of relevant costs
Source: Own presentation

If every created level of automation in the matrixes is supplied with costs, the result will be the elaboration of all the relevant costs that are differentiated to resources subject to the different levels of automation. By adding up the different costs of all stations to a total sum the most economic solution and with it, the most economic level of automation can be examined.[12] But before starting the examinations of the three production sites the next chapter will show relevant differences in a short comparison.

5.1.2 Comparison of the three production sites regarding costs

This chapter is about some site-related factors that have to be considered in a further analysis.

Generally, the regional demands of products decide on the size of the manufacture. The manufacture in Wolfsburg is considerably larger than the one in Uitenhage, because the plant in Uitenhage only supplies the local market and parts of the Japanese and Australian markets. Different demands lead to consequences with regard to the organisation of the manufacturing as well. In Uitenhage for example, it is sufficient to assemble on only 1 line with a considerable larger cycle time than in Wolfsburg, which results in a considerably smaller output than in Wolfsburg. The longer the cycle time, the more operations can be done in a cycle, or the the fewer automated operations can be carried out. The shorter the cycle time the more operations have to be subdivided into more cycles, or rather the more workers are necessary to carry out the operation in a given station. But, there is also a limit to the number of workers at a station depending on the operations they have to carry out or else the workers can

[12] See Hartmann 1993, pp. 112

obstruct each other with respect to the smooth work- flow. These conditions have to be considered in the further analysis because they can influence costs considerably.

Personnel costs are the largest in the Golf A5 production in Wolfsburg. Although the Auto5000 GmbH is on the same location, personnel costs are smaller there because of the different types of production and work.[13] The lowest personnel costs of the three analysed production sites are to be found in Uitenhage, where, as a consequence, the assignment of personnel or rather manual operations is much more reasonable. Besides defending existing market shares and exploiting new ones, the low personnel costs are a good reason for shifting production into foreign countries as a reaction to the high costs per unit in Germany.[14] There, high working costs combined with a noticeable reduction of working hours take an international top position. A very good example of this is the Golf A5 production in Wolfsburg, where working hours amount to an average working time of 28.8 hours per four-day week, a factor, which is to be valued in proportion to the highest wages of all analysed production sites.[15] Small working hours cause high down times of machines as well.[16] But, on the other hand, high working costs should be no problem for German companies if the costs per unit and, especially the fixed costs, are below the costs of the competitors. This is only possible by ensuring a productivity that is above average.

Differences between the three production sites are also to be found in the relationship between gross and net personnel. The net personnel are the amount of people that are needed in the normal production process. But, due to sick leave, holidays and training programmes, more people are required. The percentage that has to be added to the net personnel to get the required gross personnel is different in each production site. The reasons are explained in the relevant chapters for each production site.

Investment costs for operating material mainly depend on the kind of operating material and not on the production site. But, if machines are not produced or rather sold in the same country where the production site is, then additional costs for transport and duty are relevant. But in the Uitenhage site, all machines of the assembly line, except for small parts, are bought in South Africa from mostly German company branches.[17] Therefore, transport costs and duties are not relevant for this master thesis. However, if a certain operation is realised in exactly the same way as in the Auto5000 GmbH, the

[13] See Ch. 3
[14] See Springer 1999, pg. 59
[15] See Ch. 3
[16] See Ch. 4.1.1
[17] Details from Volkswagen AG Wolfsburg and Uitenhage, department Planning

same investment costs are assumed for the operation in Uitenhage. The bases for these operations are the investment costs of the Auto5000 GmbH for the calculation of the costs due to the different levels of automation in the South African plant. The reasons for this assumption are:

- Better comparability
- The data from Auto5000 GmbH is more exact than that from Uitenhage
- Possible transport costs that are included in the investment costs of machines from a branch of a German company cannot be dealt with separately. Furthermore, the transport costs for operating materials, which are necessary for the calculation of the other levels of automation or rather the prices for this material from a local branch, are not available.

Taking this assumption into account, **Appendix D1** shows the total investment costs in each relevant station of each production site.

The electric power consumption of the machines of each station P_{Ej} is shown for each production site in **Appendix D2**. Combined with the energy cost rates for power and work, the energy costs per unit can be calculated with Formula 21. The energy cost rates of the Golf A5 in Wolfsburg are equated with the rates of the Auto5000 GmbH in Wolfsburg, because both assembly lines are on the same location. In the Golf A5 manufacturing line in Uitenhage the calculation is made with a different energy cost rate.

The electric power used to produce compressed air at each station P_{OSj} is shown for each production site in **Appendix D3**. Combined with the energy cost rates for power and work the energy costs per unit can be calculated with Formula 25.

After this comparison of the 3 production sites the analysis of every single production site can be carried out in the following chapters.

5.1.3 Analysis of the Golf A5 assembly line in Wolfsburg

In this chapter, the optimal levels of automation are calculated in each Assembly Part of the production site of the Golf A5 assembly line in Wolfsburg. The analysis starts with the determination of optimal levels of automation for the created levels shown in the matrixes in Appendix C1-C3.

The concept of the calculation is aligned with the assumption of a faultless assembly on a long-term basis. It is faultless because the number of units n is directly proportional to the cycle time, which can be seen in Formula 11. This calculated number of units n is the maximum number that can be produced within a certain cycle time. Therefore, no defects are assumed whilst assembling. The workers are completely flexible, which means that workers are employed or, rather, made redundant depending on the number of units. Because of the mentioned connections, this concept is designed for:

- Analysis of the assembly line for a new or following product
- Reviewing the existing assembly line with regard to its most economical design

The different costs for each level of automation are calculated in tables . Each level in each Assembly Part has its own table as shown in **Appendix E1-E17**. All necessary data for each calculation, which is constant for each level of automation in all Assembly Parts, is subsumed under the field called **parameters**. This field, which is placed above each table, is shown in Fig. 5.5. The parameters include the **cycle time t_C**, **shift time t_{SH}**, **number of shifts n_S** and **working days d_W**. These parameters are needed to calculate the **number of units n**, which are also included in the parameters.[18] Furthermore, all **personnel cost rates** are parameters. For calculating investment costs, amongst others, the **period of depreciation a** is necessary.[19] **Energy cost rates** for power and work are needed for calculating energy costs and operating supplies.[20] **Total investment costs** and **total equipment costs** are used for the calculation of equipment costs per unit.[21]

Parameters:					
Cycle time t_C	**1,143**	min/unit[1]	number of units **n**	190341	unit/year
Shift time t_{SH}	**392**	min/shift			
Number of shifts n_S	**3**	shifts/day			
Working days d_W	**185**	days/year[2]			
Personnel costs rate IE C_{P_IE}	**77000**	€/year[3]			
Personnel costs rate master C_{P_M}	**74500**	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**55400**	€/year			
Personnel costs rate depositor C_{P_D}	**50100**	€/year			
Period of depreciation **a**	**7**	years[4]			
Total investment costs C_{INV_WOB}	**19002600**	€[5]			
Total equipment costs C_{EQ_WOB}	**390000**	€/year[6]			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_WOB}	**46**	€/kW*year[7]			
Energy costs rate C_{W_WOB}	**0,070**	€/kWh			

[1]: Cycle time and shift time from Volkswagen AG Wolfsburg, department Industrial Engineering
[2]: Working days calculated by considering weekends, free Fridays, holidays and shut down
[3]: Personnel cost rates from Volkswagen AG Wolfsburg, department Controlling
[4]: Details from Volkswagen AG Wolfsburg, department Controlling
[5]: Total investment costs: See Appendix D
[6]: Total equipment costs: See Chap. 5.1.1
[7]: Energy costs rates of WOB from Volkswagen AG Wolfsburg, department Maintenance

Fig. 5.5 Parameters for the assembly line of the Golf A5 Wolfsburg
Source: Own presentation

Basically, every table for calculation has the same structure. All costs are assigned to stations and broken down into units. Hence, there are no general expenses, only direct expenses.

On top of each table, the different relevant types of costs are sorted according to resources (see Fig 5.6). For every type it is mentioned if the costs of a certain type are variable costs per unit (c_{var}) or fixed costs per unit (c_{fix}).

[18] See Formula 11
[19] See Formula 20
[20] See Formula 21 and 25
[21] See Formula 22, 23 and 24

Personnel costs											
Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})	Main & ser…
t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}			
[illegible]								[illegible]			

Fig. 5.6 Top of the table
Source: Own presentation

Direct workers on the line and QCC workers are only relevant for manual stations, which are coloured yellow as can be seen in the matrixes in Appendix C1-C3. In contrast to this, reworkers, depositors as well as other workers, who are mainly machine operators, are only relevant for automated stations. On the right, the different stations of the given Assembly Part are shown (see Fig. 5.7). In every field, except for the bold typed fields, the costs per unit for each type of costs in each station are calculated. The necessary formula to calculate the certain costs is shown on top of each column (See Fig. 5.6). These formulas are presented in Ch. 5.1.1. In the bold typed fields the parameters have to be entered to enable the calculations. These parameters can be taken from Appendix D1-D3 and from the matrixes in Appendix C1-C3. At the bottom of the table, all costs of a certain type are added up to total costs. However, the sums of all personnel costs are net cost. Therefore, all personnel costs are additionally multiplied with the percentage rate of 11% and added to the net sum to get the total gross costs per unit (see Fig. 5.8). On the right side, all costs per unit of a certain station are added up. These total costs already consider the percentage of

Station
Rollforming tailgate
Fitting cockpit location brackets
Rollforming doors
Cleaning window flange, Closing tailgate
Priming window flange, Opening bonnet
Applying cockpit glue
Cockpit fitting 1
Cockpit fitting 2
Removing cable box, Remaining screw connections
Remaining screw connections

Fig. 5.7 Left side of the table
Source: Own presentation

personnel costs. Therefore, these costs are already gross costs. The sum of this column represents the total costs per unit of a certain level of automation of a certain Assembly Part, which is shown at the bottom of the page. The table is divided so that all stations, at different levels of automation and within the parameters of the given production site, are combined as a single, coherent table (see Fig. 5.9).

Total net costs per unit:	1,76 €	0,11 €
Total gross costs per unit (+11%):	1,95 €	0,12 €

Fig. 5.8 Sums of each column and converting them into gross costs
Source: Own presentation

Stations with parameters that are taken from Golf A5 Wolfsburg:										
	Pers…									
Station	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})			
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_M…	
	$c_{P\_...} = \frac{t_{M\_...} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P_DJ} = $…	
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,…
Cleaning window flange, Closing tailgate	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00
Priming window flange, Opening bonnet	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,…
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €		
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	…	
Removing cable box, Remaining screw connections	2,325	1,78 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00

Stations with parameters that are taken from Auto5000 Wolfsburg:										
	Perso…									
Station	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		D…	
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	
	$c_{P\_...} = \frac{t_{M\_...} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_DJ} = \frac{t_M}{t_{SH}}$…	
Rollforming tailgate	1,07	0,82 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,0…
Rollforming doors	2,4	1,83 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 …

Fig. 5.9 Divided stations
Source: Own presentation

By adding up all total costs per unit of each station the total costs per unit of the whole Assembly Part are determined for the given level of automation.

The total costs per unit of each Assembly Part for each level of automation are shown in Fig. 5.10 and Tab. 5.3 respectively. The result of the analysis is that there are three levels of automation, one for each Assembly Part.

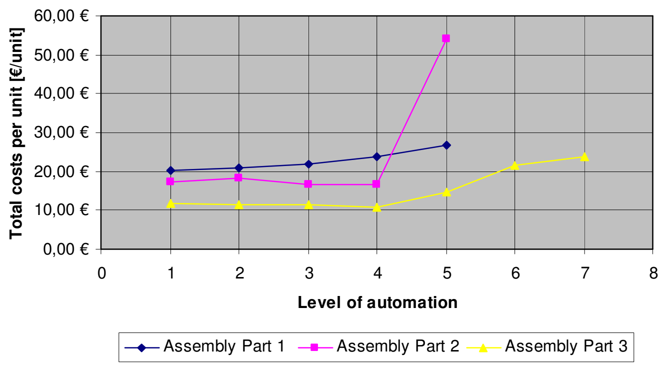

Fig. 5.10 Total costs per unit versus level of automation (Assembly Part 1-3)
Source: Own presentation

Level of automation	Assembly Part 1	Assembly Part 2	Assembly Part 3
1	20,38 €	17,22 €	11,63 €
2	20,77 €	18,19 €	11,48 €
3	21,78 €	16,67 €	11,48 €
4	23,70 €	16,60 €	10,64 €
5	26,64 €	54,11 €	14,58 €
6			21,37 €
7			23,77 €

Tab. 5.3 Overview of total costs per unit
Source: Own presentation

As can be seen, for Assembly Part 1, the first level of automation is the optimal level of automation because this level has the lowest costs (red graph). This level also predominates in practice (see dotted field in Tab. 5.3). Therefore Assembly Part 1 or rather Mechanisation 1 is designed optimally. In Appendix E1 you can see that the other workers and the investment costs cause the highest share of the total costs per unit. The cockpit fitment is the most expensive station in this Assembly Part. By comparing Appendices E1-E5 with each other, one can see that with a decreasing level of automation both the indirect workers' and the investment costs have a gradually smaller share but costs for direct workers on the line increase over-proportionally. This is the main reason why even the second level of automation is more expensive than the first one. The other types of cost only represent small parts in the total costs per unit.

In Assembly Part 2 the fourth level of automation is optimal. It is 0.62 € per unit and more economical than in the existing first level of automation. Although the costs of workers on the line increase with a lower degree of automation, whereas costs for other workers and investment costs decrease, that increase as such is not that strong. To reach the optimal level of automation those stations stamping VINs, fitting gearshift, closing bonnet and fitting all windows have to be organised in the same way as on the assembly line of the Auto5000 GmbH. Due to the extensive operations concerning the manual fitting of the powertrain and the underbody work the result is a large difference between the fourth and the fifth level. Too many workers on the line are required for these extensive operations, as can be seen on the assembly line of the Golf A5 in Uitenhage.[22]

In Assembly Part 3, the fourth level of automation is also optimal. This level, which exists in practice, is 0.99 € per unit more economical than the first level. On the

[22] See Appendix E6-E10

first level, the investment costs cause the highest share of the total costs per unit, followed by the personnel costs for maintenance workers, reworkers and other workers. As in Assembly Part 2, the costs for workers on the line increase with a decrease in automation, whereas costs for reworkers, other workers and maintenance decrease until the cost optimum is reached on level 4. After that the costs for workers on the line increase over-proportionally, which makes every further deautomation uneconomical. To put level 4 as an optimal level of automation into practice, the stations opening bonnet, putting in and fitting CW trim panel, putting in and fitting battery, fitting cross member as well as fitting rear bumper have to be designed in the same way as in the Auto5000 GmbH.[23]

5.1.4 Analysis of the Touran assembly line Auto5000 GmbH in Wolfsburg

The analysis of the assembly line of the Touran in the Auto5000 GmbH is carried out in exactly the same way as the analysis of the assembly line of the Golf A5 in Wolfsburg. All the examinations are carried out on the same basis and will show the results in a similar way. Thus, this method will ensure a better comparison of the three production sites, which also allows each of the relevant chapters to be structured in the same way for all three sites of production.

The different costs for each level of automation are calculated in the same tables as the tables of the Golf A5 assembly line in Wolfsburg (see Appendix E1-E17). However, the parameters (which include all the necessary data for the calculation that is constant for each level of automation in all Assembly Parts) are different in each production site. In each production site the cycle times, days, shifts and especially the personnel cost rates are distinguished from each other. The parameters of the Wolfsburg production site are shown in Fig. 5.11 (see previous page). The percentage to calculate the gross personnel from the net personnel is 4% in

Parameters:					
Cycle time t_C	1,380	min/unit[1]	number of units **n**	205565	unit/year
Shift time t_{SH}	394	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	240	days/year[2]			
Personnel costs rate IE C_{P_IE}	77000	€/year[3]			
Personnel costs rate master C_{P_M}	56000	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	45000	€/year			
Personnel costs rate depositor C_{P_D}	45000	€/year			
Period of depreciation **a**	7	years[4]			
Total investment costs C_{INV_WOB}	19002600	€[5]			
Total equipment costs C_{EQ_WOB}	390000	€/year[6]			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate $C_{POW\_Auto5000}$	46	€/kW*year[7]			
Energy costs rate $C_{W\_Auto5000}$	0,070	€/kWh			

[1]: Cycle time and shift time from Volkswagen AG Wolfsburg, "Lernstatt"
[2]: Working days calculated by considering weekends, holidays and shut down (working 1 shift on some Saturdays also considered)
[3]: Personnel cost rates from Volkswagen AG Wolfsburg, department Controlling
[4]: Details from Volkswagen AG Wolfsburg, department Controlling
[5]: Total investment costs: See Appendix D
[6]: Total equipment costs: See Chap. 5.1.1
[7]: Energy costs rates of Auto5000 from Volkswagen AG Wolfsburg, department Maintenance

Fig. 5.11 Parameters for the assembly line of the Auto5000 GmbH Wolfsburg
Source: Own presentation

[23] See Appendix E11-E17

the Auto5000 GmbH. It is much smaller than on the Golf A5 assembly line because of a longer shut down.

As already mentioned, all the tables of each level of automation and each Assembly Part are equal, including all the parameters, because the defined levels of automation are valid for all production sites. The tables are in **Appendix F1-F17**. The total costs per unit of each Assembly Part for each level of automation are shown in Fig. 5.12 and Tab. 5.4 respectively.

As can be seen with regard to Assembly Part 1 the third level of automation is optimal (red graph). On this level there is a preponderance of labour costs per unit, followed by the investment costs. In practice, however, level 4 is carried out, which makes a distinction in costs of 0.19 € (dotted field). To reach the optimal level, the stations fitting cockpit location brackets and cockpit fitting 1 and 2 have to be designed fully automatically as it is done in the Mechanisation 1 of the Golf A5 assembly in Hall 54.[24]

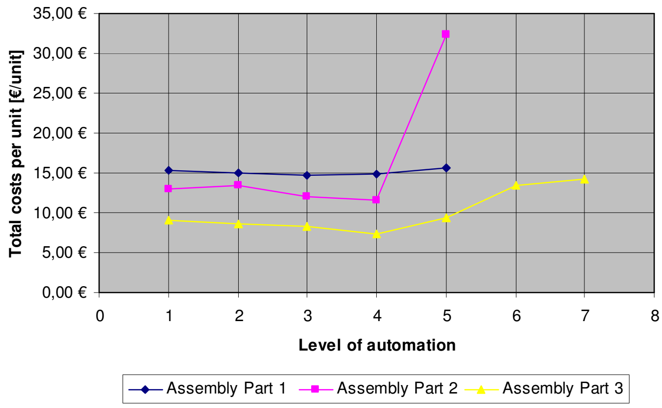

Fig. 5.12 Total costs per unit versus level of automation (Assembly Part 1-3)
Source: Own presentation

Level of automation	Assembly Part 1	Assembly Part 2	Assembly Part 3
1	15,37 €	12,97 €	9,02 €
2	15,04 €	13,40 €	8,57 €
3	14,72 €	12,09 €	8,24 €
4	14,91 €	11,63 €	7,29 €
5	15,70 €	32,31 €	9,37 €
6			13,43 €
7			14,20 €

Tab. 5.4 Overview of total costs per unit
Source: Own presentation

In Assembly Part 2, the fourth level of automation is the optimal level of automation. This level also predominates in practice. Therefore, Assembly Part 2 is designed optimally. The most expensive station of this Assembly Part is fitting the complete power train combined with all the underbody work. As on the assembly line of the Golf A5 in Wolfsburg, the high personnel costs of workers on the line cause the large difference in cost between level 4 and level 5.[25]

In Assembly Part 3, the fourth level of automation also represents the optimum. But in practice level 6 predominates, which causes more automation on the assembly line of the Touran in the Auto5000 GmbH. On level 6, the installation of the front-end is the most expensive station because of the high personnel costs for workers on the line.

[24] See Appendix F1-F5
[25] See Appendix F6-F10

The second most expensive station is the premounting and fitting of wheels. Both of the stations require high investment costs as well. Therefore, both of these stations and the station where the spare wheel is placed in the boot have to be carried out automatically as in Mechanisation 3 on the Golf A5 assembly line. (in the same location.) Then, 6.14 € per unit can be saved.[26]

5.1.5 Analysis of the Golf A5 assembly line in Uitenhage, South Africa

The analysis of the assembly line of the Golf A5 in Uitenhage is carried out in exactly the same way as in both of the other production sites. All examinations are made on the same basis and will show the results in a similar way.

The different costs for each level of automation are calculated in the same production tables as the production tables of the other two production sites. The parameters of Uitenhage are shown in Fig. 5.13. The percentage rate to get the gross personnel from the net personnel is 5% on the assembly line in Uitenhage.

Parameters:					
Cycle time t_C	4,550	min/unit[1]	number of units **n**	50549	unit/year
Shift time t_{SH}	460	min/shift			
Number of shifts n_S	2	shifts/day			
Working days d_W	250	days/year[2]			
Personnel costs rate IE C_{P_IE}	33500	€/year[3]			
Personnel costs rate master C_{P_M}	15200	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	14400	€/year			
Personnel costs rate depositor C_{P_D}	14400	€/year			
Period of depreciation **a**	7	years[4]			
Total investment costs C_{INV_WOB}	19002600	€[5]			
Total equipment costs C_{EQ_WOB}	390000	€/year[6]			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_SA}	62	€/kW*year[7]			
Energy costs rate C_{W_SA}	0,027	€/kWh			

[1]: Cycle time and shift time from Volkswagen AG Uitenhage, department Industrial Engineering
[2]: Working days calculated by considering weekends, holidays and shut down
[3]: Personnel cost rates from Volkswagen AG Uitenhage, department Controlling
[4]: Details from Volkswagen AG Wolfsburg, department Controlling
[5]: Total investment costs: See Appendix D
[6]: Total equipment costs: See Chap. 5.1.1
[7]: Energy costs rates of SA from Volkswagen AG Uitenhage, department Planning

Fig. 5.13 Parameters for the assembly line of the Golf A5 assembly line Uitenhage
Source: Own presentation

The tables can be seen in **Appendix G1-G17**. The total costs per unit of each Assembly Part for each level of automation are shown in Fig. 5.14 or Tab. 5.5 on the following page.

[26] See Appendix F11-F17

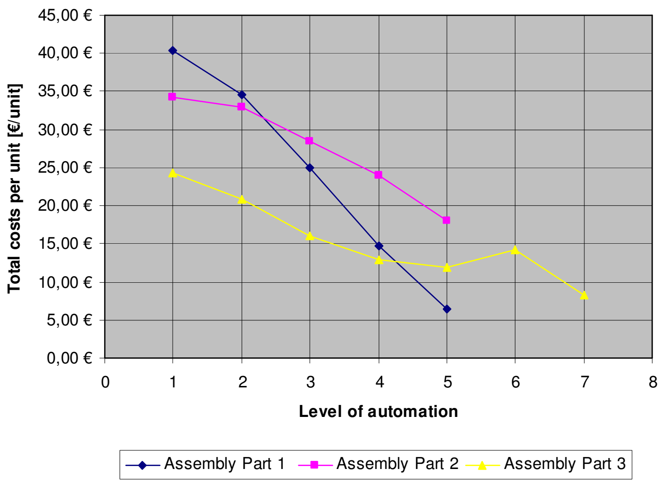

Fig. 5.14 Total costs per unit versus level of automation (Assembly Part 1-3)
Source: Own presentation

Level of automation	Assembly Part 1	Assembly Part 2	Assembly Part 3
1	40,36 €	34,17 €	24,38 €
2	34,56 €	32,95 €	20,81 €
3	24,94 €	28,39 €	16,01 €
4	14,76 €	24,05 €	12,98 €
5	6,48 €	17,96 €	11,90 €
6			14,25 €
7			8,22 €

Tab. 5.5 Overview of total costs per unit
Source: Own presentation

As can be visualised, in each Assembly Part the lowest level of automation is the optimal level, which is the current situation. Therefore, no changes of stations or operations are necessary in this phase of the analysis. It is left open if less automation leads to even more reduction of costs in any Assembly Part. However, this question cannot be answered because, on the one hand, there is no data about manufacturing times and costs for facilities with even less automation, and, on the other hand, there are even less possibilities for more deautomation without causing a negative effect on quality. In Assembly Part 1 the most expensive station is fitting the cockpit.[27] It causes nearly half of the total costs per unit. In Assembly Part 2, fitting the powertrain combined with the whole underbody work causes the highest costs per unit, which is even more than half of all total costs per unit.[28] In Assembly Part 3, premounting and fitting wheels show the highest part of the total costs.[29]

This is the end of the analyses of costs. In the following chapter, the quality aspect will be examined.

5.2 Examinations and results of quality

The following list of the decisive quality factors used by VW is not complete. On the one hand the chosen factors are especially selected for the influences of the automation level of the assembly lines as regards the quality of product. On the other hand there are other factors in the VW group used for the determination of quality.

[27] See Appendix G5
[28] See Appendix G10
[29] See Appendix G17

5.2.1 Instruments for the determination of quality in the VW Group

FISeQS data[30] (**F**ahrzeug **I**nformations**S**ystem **e**lektronische **Q**ualitäts**S**icherung)

This system is meant for the intrusion and the analysis of high-quality key data defect entering, part of building entering, blocking and checking as well as facility results in the vehicle production. The increasing number of equipment variants and types, which cause new requirements on the part of Quality Assurance, are the reasons for the development of this information system. Targets of this system include:

- Recording (of) defects in origin
- Updating the history of defects and list of open defects per vehicle
- Generating vehicle-specific checklists as well as recording and analysing the checked results
- Making suggestions about rework places
- Blocking vehicles

As soon as the defect is recognized it should be immediately rejected and documented. Defects should be entered when they are:

- Not rejected at once; no defective vehicles are handed over
- Immediately rejected, but the defects are not caused at this place; on advice because of deplorable conditions which have to be repaired
- Expensive; loss of time has to been explained
- About safety issues; cause for a possible re-examination

Trouble cases are entered in standard-defect catalogues by a “handheld” (portable entry-appliance) or in the FISeQS. The FISeQS contains all trouble cases. It does not matter into which system occurring defects are entered for further careful consideration since they are clearly assigned to the agent where the defect is caused. So, the data is very well suited to allow a thorough investigation into the interdependency between the level of automation and amount of defects.

My Process data[31]

This system is designed for the entering and analysis of quality covered data in the vehicle manufacturing of the Auto5000. It is comparable with the FISeQS at VW. Defects are entered and assigned to the responsible agent in exactly the same way as with the FISeQS. Otherwise my process would contain defects of the QCC-lists,

[30] See FISeQS Anwenderhandbuch
[31] My Process V2.1 in der Montage

Analyses and FISeQS. My process gives the user more possibilities of analysis (e.g. QCC, etc):

- History of past defects?
- Recording of Team related defects?
- Identification of post-Assembly defects?

These analyses are both process- and function-orientated. For this thesis only function-orientated analyses like FISeQS are used. My process contains all trouble cases, which are caused during the assembly. These are assigned to their causing agent. Therefore, they are clearly assignable to the individual assembly steps in order to be considered. Thus, these collected data are very well suited to allow a thorough investigation into the interdependency between the level of automation and amount of defects.

Vehicle-Audit data[32]

Vehicle auditing is an element of the Quality Assurance System, which evaluates the effectiveness of QM-systems on the basis of delivered quality vehicles in a snapshot. According to the VW guideline, 10 vehicles per model per month have to be checked in the audit. The results are made public inside the factory and shall show the trouble cases to enable the manufacturing process to correct them. The result of this should be an increase in the quality of products ready for delivery. On the other hand, a Vehicle-Audit is addressed outside the factory as well and takes into consideration the demands of the customer who takes possession of the vehicle. The company determines these demands. Therefore, a Vehicle-Audit is also an actual target comparison between the targets and the actually manufactured quality. The quality ready for delivery is shown by an index: the quality class. This is the result of the sum of trouble-cases of an audit. Quality class is an index of the quality of products ready for delivery with regard to vehicle-manufacturing plants. Productive conditions are not taken into account. There is only one audit-scale used, which is independent from the audited vehicle or rather the vehicle class and equipment. The assessment of performance is run on an agreed quality scale, which is carried out with checklists and is user-orientated. The checklists, the guideline for the user and the procedure as such are the same to guarantee the comparability of the results.

[32] Richtlinie Fahrzeugaudit, details from Volkswagen AG Wolfsburg, department Quality

Data of Vehicle Preparation Centre (VPC) in Japan[33]

VPC was founded owing to the long distances of transport from plant to market, during which the product quality gets damaged. It fulfils the local demands (for example demands of local laws, TÜV, stick-on badges, etc.) on the vehicle, which cannot be given at the place of production. Every vehicle, which is delivered in Japan, is checked in the VPC. The VPC controls the local quality demands and damages caused by transport. The basis of this checking procedure is the standard complaint catalogue, which is made on the basis of customer complaints. The VPC records delivery flaws of vehicles from Wolfsburg (Golf A5 and Touran) and Uitenhage (Golf A5) in a 100% control. These flaws are subdivided into trouble cases referring to glass, body, mechanics, polish and paint and are documented as trouble cases per vehicle. These data allow a very good comparison with other data because it is determined in the same way at the same time by the same people who use the same checklists. It is impossible to attribute this data to the assembly steps, which are to be considered, but it is possible to compare assembly-caused trouble cases with each other.

Field data[34]

Field Data are recorded in QUASI-FI (**Qua**litätsSicherung **S**teuerungs und **I**nformationssystem **F**eld**I**nformation). Field information refers to trouble cases, which are reported back to Volkswagen by the garages. This data shows the quality of vehicles from a customer's point of view. QUASI-FI is a system for the statistical analysis of these field data. The system is used for the observation of quality data worldwide. Because these data come from the field, they are delayed and do not show the actual state of production. QUASI-FI data can be used for analysing different Top Lists. In this paper the Top500 List is used for the analysis. The Top500 list[35] shows the kind and number of individual trouble cases (called Schadensfall (SF)) as well as their percentage part of all SF. The six columns on the right hand side show the percentage of the different SF-types per each SF.

It is problematical that this data cannot be classified as exactly as FISeQS-Data. However, you can compare the possibility of assembly-caused trouble cases with each other.

[33] Details from Volkswagen AG Wolfsburg, department Quality
[34] Details from Volkswagen AG Wolfsburg, department Quality
[35] See Appendix A8 ;only a part of Top500 List as an example is shown because these are confidential information; for need please contact department GQA-41, VW Wolfsburg

Direct-Runner-Rate data[36]

The definition of the Direct-Runner Rate (DRR) on Checkpoint 8 in the Volkswagen Group is:

> The Direct-Runner Rate is the ratio of the sum of all vehicles with the status V900 without a status Z800 to the sum of all vehicles with the status V900.

Status V900 describes an o.k.-vehicle, which is collected by the sales department. Status Z800 describes an o.k.-vehicle, which is turned away at Checkpoint 8 (CP8). DRR indicates the number of vehicles, which get an o.k.- status during the first checking at CP8. In the view of manufacturers a checkpoint is a stepwise process to confirm that all the assembly steps have been achieved. CP8 is located at the vehicle-exit point.

CP7 is located at the end of the vehicle assembly. The definition of DRR at CP7 is the same as above, but the stations are named differently. DRR on CP7 is included in our consideration to show how many o.k.-vehicles are released from the assembly. DRR is an index by which each plant is measured. It has to be seen in the context of the flow of process, because each part influences the other depending on the place of rework. So, in connection with the flow of process this rate is a good comparison of different production places.

Process-Audit data[37]

Effectiveness of management systems for quality and the assessment-to-assessment of manufacturing processes occur by Process Audits. In these processes methods and products are checked. The main emphasis is put on process safety in the individual production phases. The procedure is (like Vehicle Audit) identical across the group. Hence, the comparability of results is guaranteed. Every product group and all manufacturing steps within have to be examined by the Quality Assurance with an audit at least once per year by the Quality Assurance at the prevailing location. Process audits are carried out for the assessment of quality ability of manufacturing processes. The result is the degree of total realisation. A snapshot of the degree of the achievement of objectives is shown with regard to such aspects as ability and process control. Since the assembly processes are not the same as the steps of process audits some parts have to be looked at in detail. But these process steps of the Process Audit are the same because of the guideline for the whole group. So, the results are comparable as long as it is recognized that the sphere of the assembly steps is always included.

[36] Details from Volkswagen AG Wolfsburg, department Quality
[37] Konzern-Richtlinie Prozessaudit, details from Volkswagen AG Wolfsburg, department Quality

5.2.2 Determination of quality

This part shows the determination of quality in the examined Assembly Parts. The procedure, determination and results are explained.

Procedure of determination

On the basis of the first analysed matrixes as described above the quality factors are collected, which can be assigned to the individual fields of matrixes. Owing to the detailed and complete recording these data are entered in FISeQS[38] and in my process, too[39]. These data include all assembly defects that arise in the examined Assembly Parts.

In the next step, factors the VW group uses for the determination of quality[40] are included for consideration.

From a practical point of view the presentation of the actual results takes place before their determination in order to find the optimal level of automation.

Finally, a purely theoretical determination with regard to finding the optimal level of automation takes place.

Explanation of determination

This determination is shown as an example in Assembly Part 1.

By the detailed termination of defects and their assignment to the causing agent, it is possible to refer trouble cases directly to the individual stations[41] (column in the matrix). To create a comparable unit, the number of trouble cases is divided in the same period of time by the number of vehicles produced [42]. The following figure is developed.

[38] See FISeQS data
[39] See My Process data
[40] See Vehicle-Audit data, VPC, Field data, Direct-Runner-Rate data, Process-Audit data
[41] See Appendix H4
[42] See Appendix H13

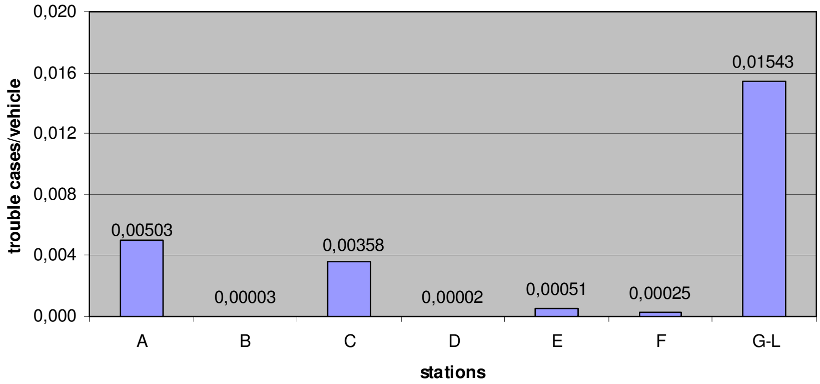

Fig 5.15: Trouble cases per vehicle of level of automation Golf A5 WOB in Assembly Part 1
Source: Own presentation

This figure shows the trouble cases per vehicle in each individual station. These are the results, which are later listed in the matrix. Thus, all the fields of the level of automation of the Golf A5 WOB can be filled into the matrix of Assembly Part 1.

Analogue to the described procedure for the level of automation of the Golf A5 WOB, the other levels of automation for Auto5000 WOB[43] and Golf A5 SA[44] are analysed. Therefore, the matrix of Assembly Part 1[45] referring to assembly defects is completed.

Exactly the same procedure is followed for filling in the other two matrixes for Assembly Part 2[46] and Assembly Part 3[47].

The results in Assembly Part 1[48] are that the level of automation of the Golf A5 WOB had the lowest number of defects in 2005, on average 0.02484 trouble cases per vehicle. The level of automation of the Golf A5 SA created the most trouble cases with 0.11275 per vehicle.

Please note: “n.a.” means “not available”. In the Auto5000 the cockpit location brackets are not assembled because the Touran does not have any. Furthermore, the window flanges are cleaned only in the Golf A5 WOB assembly. Some steps caused “no defects”, so “n.d.” is listed in the steps. The trouble cases caused by all steps belonging to cockpit fitting are summarized in the penultimate field.

In Assembly Part 2[49], Auto5000 WOB has the best value with 0.02330 trouble cases per vehicle. With a value of 0.03769 the Golf A5 WOB has the worst value. The meanings of “n.d.” and “n.a.” are explained above. In this case no defects are available for fitting side windows in the Golf A5 SA because in Uitenhage only 4-door models are manufactured.

[43] See Appendix H7 and H13
[44] See Appendix H10
[45] See Appendix H14 and H15
[46] See Appendix H16 and H17 out of H5, H8 and H13 as well as H11
[47] See Appendix H18 and H19 out of H6, H9 and H13 as well as H12
[48] See Appendix H14
[49] See Appendix H16

The most trouble cases in Assembly Part 3[50] were made with respect to the level of automation of the Golf A5 SA with a value of 1.54291 trouble cases per vehicle. The best value is 0.00737 trouble cases per vehicle caused by the level of automation of the Golf A5 WOB.

In the next step the data was analysed, which is used for the determination of quality in the VW group[51]. This data cannot be analysed by each individual station but only within the assembly in general. The procedure, explanation and meaning of each kind of data are shown as an example on the level of automation of the Golf A5 WOB.

Vehicle-Audit data

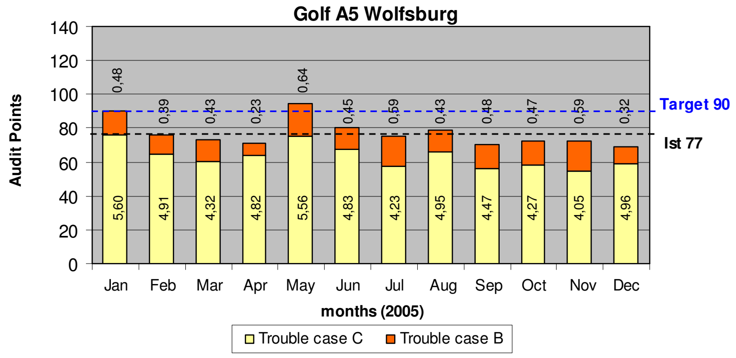

Fig. 5.16: Audit points of Golf A5 WOB assembly
Source: Own presentation

Explanation of the average number gained in January:

- 5.60 is the ø-number of C-defects in this month, the yellow part of the pillar shows the number of Audit Points caused by C-defects
- 0.48 is the ø-number of B-defects in this month, the red part of the pillar shows the number of Audit Points caused by B-defects
- The height of the whole pillar describes the ø-sum of Audit Points per months
- 90 is the target, which caused Audit Points in the assembly that should not exceed. This value is typical for the Golf A5 in WOB. The Touran assembly has the target of 113 Audit Points and the Golf A5 in SA of 94 Audit Points. On the one hand, the differences are explicable by the different determination of reaching the target and, on the other hand, by the slight different conceptions of vehicles. That is why the Audit Points

[50] See Appendix H18
[51] See Vehicle-Audit data, VPC, Field data, Direct-Runner-Rate data, Process-Audit data

cannot be compared with each other directly, but they have to be put in connection with the target. So, it can be visualised how well the guideline is fulfilled.

- 77 is the actual (Ist) value, which the Vehicle-Audit-checked vehicles had on average in the year 2005

The fewer defects, the fewer Audit Points, because every kind of defect gets a particular number of Audit Points[52]. In comparison with the target, the level of automation, which has the best Audit results, can be determined. The determined figures[53] show that the level of automation of the Golf A5 WOB delivers the best result, because the actual value 77 is 14% lower than the target 90. The level of automation of the Golf A5 SA delivers an actual value of 96, which is 2% higher than the target 94 and hence, the worst value.

VPC data

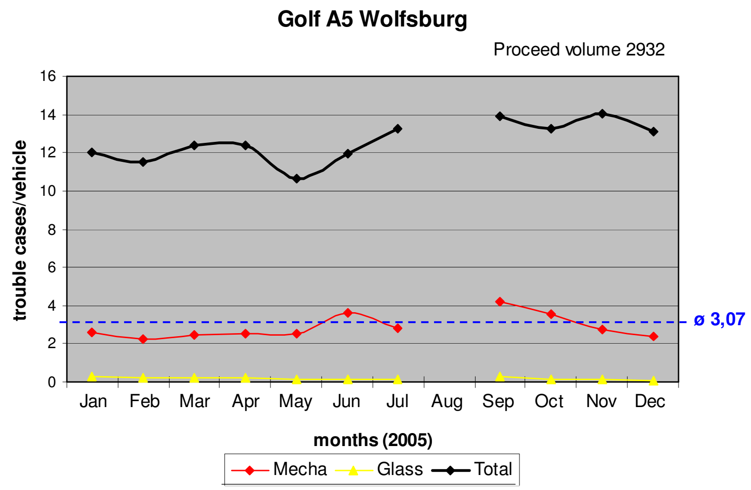

Fig. 5.17: VPC data of Golf A5 WOB assembly
Source: Own presentation

Explanation for the calculation of the average value of trouble cases:

- Shown are the trouble cases per vehicle as applied to mechanical trouble cases (Mecha) and glass trouble cases (Glass), both of which could be caused in the assembly[54], as well as the total number of trouble cases (Total) for comparison.
- 2932 is the number of checked vehicles in 2005

[52] See Vehicle-Audit data
[53] See Appendix H22
[54] Details from Volkswagen AG Wolfsburg, department Quality

- 3.07 is the ø- number of Mecha + Glass trouble cases in 2005
- The month refers to the production months of the vehicles
- In August, no vehicles are checked because of the holiday shutdown in the VW production in Wolfsburg.

This figure is taken from the table[55], which summarises the results of the VPC reports on a monthly basis.

Like the Vehicle-Audit Data, this data is used for the better understanding of the results. The fewer trouble cases there are the better the quality of the vehicle ready for delivery. The results of the three figures[56] of VPC Data show that the level of automation at the Auto5000 WOB, with 1.31 trouble cases per vehicle, has the lowest value and hence, the best result. The worst result with 3.07 trouble cases per vehicle was the level of automation of the Golf A5 WOB.

Field data

Explanation of the average figure (gained-raus):

- Data from the Top 500 QUASI FI-list are analysed analogous to the causal agent principle (like FISeQS, my process and Vehicle-Audit data, which are applied)
- Clear trouble cases[57] caused by Assembly Parts remain

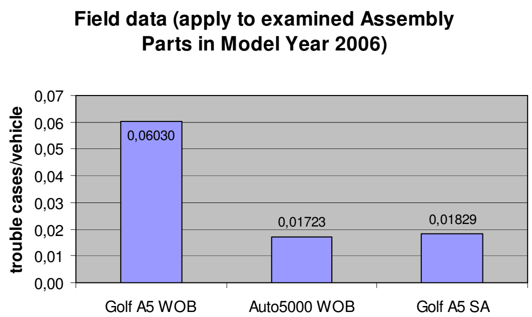

Fig. 5.18: Field data of examined Assembly Parts
Source: Own presentation

- This number of trouble cases is divided by the number of vehicles in the appropriate QUASI FI report
- Thus, the number of trouble cases per vehicle per individual assembly line in Model Year 2006 (Standing March 2006) is shown here.

The figure shows that the level of automation of the Auto5000 delivers the least trouble cases per vehicle at a rate of 0,01723 trouble cases per vehicle. Hence, this is

55 See Appendix H23
56 See Appendix H24
57 See Appendix H25

the best value. The worst value is 0,06030 trouble cases per vehicle caused by the level of automation of the Golf A5 Wob.

Direct-Runner-Rate (DRR)

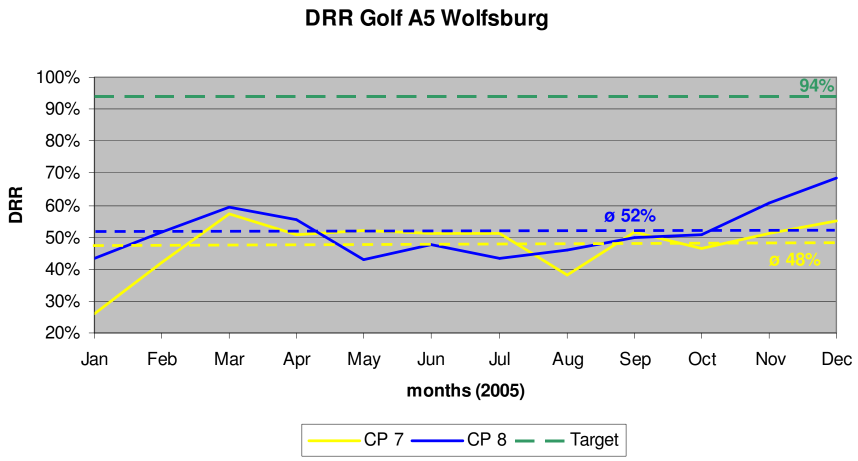

Fig. 5.19: DRR of Golf A5 WOB assembly
Source: Own presentation

Explanation of the result:

- The figure shows the course of ø-DRRs on CP7 and CP8 per month
- 94% is the target for DRR on CP8 in the Golf A5 WOB manufacture
- 52% or rather 48% are the ø-DRRs on CP8 or rather CP7 in 2005

On the one hand the courses describe how many o.k.-vehicles are handed over by assembly (DRR on CP7) and, on the other hand, how many o.k.-vehicles leave the manufacture (DRR on CP8). In the mutual courses to each other it can be seen where rework is located in the flow of process. This is also clearly shown by the accompanying flows of processes.

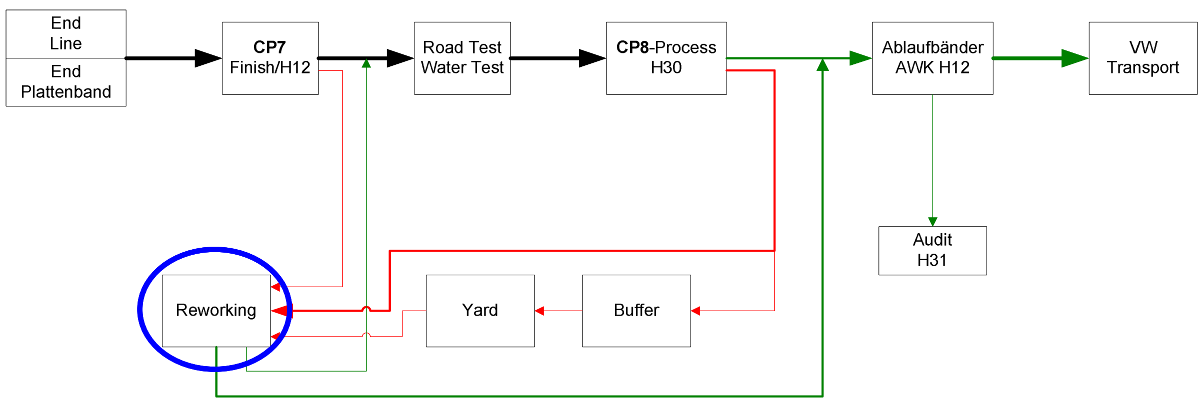

Fig. 5.20: Flow of process in the Golf A5 WOB manufacture
Source: Statuskonzept ZP7-ZP8[58]

[58] See Appendix H28

The figure shows that most of the rework takes place after CP8, and only a small number of cars are reworked after CP7. The reasons for this are the local conditions:[59] it is not possible to drive so many vehicles to the rework station from this spot, and on the other hand, rework is planned not till the whole manufacturing process has ended. So, expenditure of rework is unique.[60]

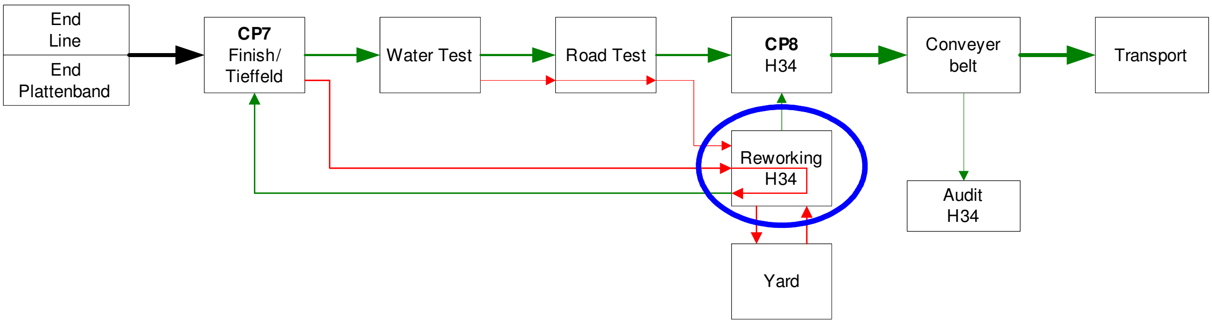

Fig. 5.21: Flow of process in the Auto5000 manufacture
Source: Statusablauf Touran[61]

The figure shows that rework takes place between CP7 and CP8. The reason is that this manufacture was planned[62] in a different way compared to the manufacture above. So, most of the rework is done before CP8.

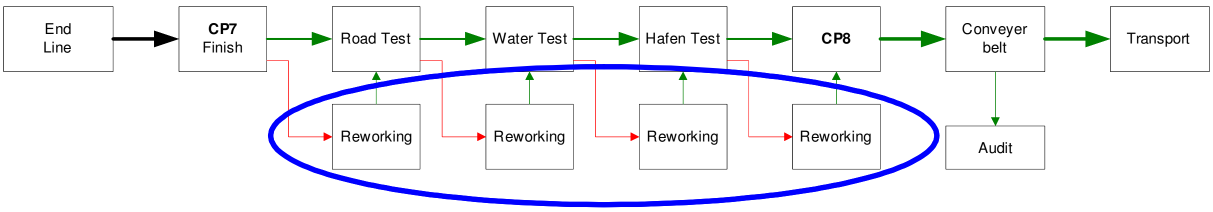

Fig. 5.22: Flow of process in the Golf A5 SA manufacture
Source: management assembly SA

Fig. 5.22 shows that, compared to the Auto5000 flow of process, most of the rework takes place before CP8.

Hence, the DRR of CP8 always has to be seen in connection with the place of rework in the flow of process. Nevertheless, this DRR receives much attention in this paper because it is a uniformly defined value[63] of quality in the VW group.

Furthermore, a statement for the quality of assembly processes by DRR on CP7 is possible. It should be noted:

- Only the Golf A5 WOB assembly has the possibilities of rework in the described places directly after the Mechanisations,
- The Auto5000 WOB assembly has two further possibilities of rework outside the described on-line rework possibilities

[59] Details from Volkswagen AG Wolfsburg department Production
[60] Details from Volkswagen AG Wolfsburg, department Production
[61] See Appendix H30 and H31
[62] Details from Volkswagen AG Wolfsburg, department Quality
[63] See Direct-Runner-Rate data

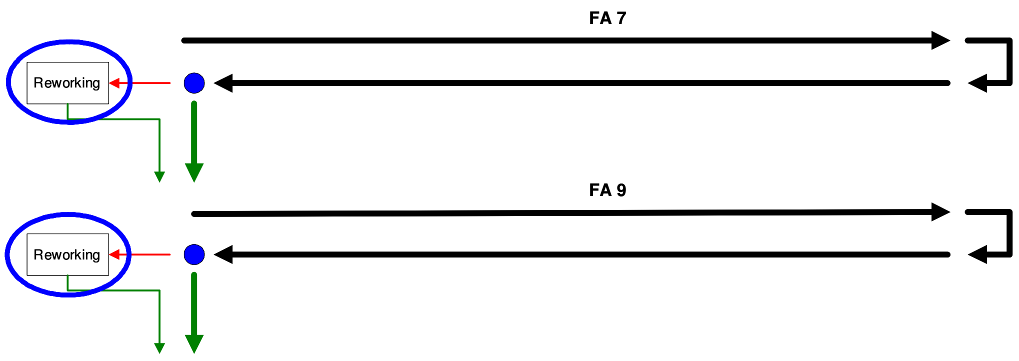

Fig. 5.23: Rework possibilities outside the line in the Auto5000 assembly
Source: Statusablauf Touran[64]

Fig. 5.24 shows that in the Golf A5 SA assembly nearly every vehicle, which has to be reworked, is directed to the end of the line and where it is reworked. This is possible by a very high circle time (ø>4,5min in 2005)[65] and the organisation in the assembly.

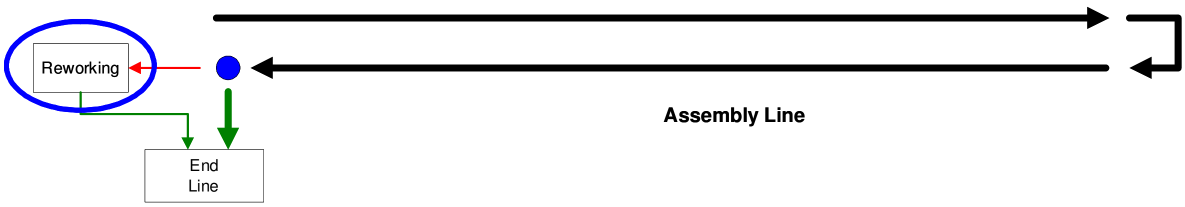

Fig. 5.24: Rework possibilities outside the line in the VWSA assembly
Source: management assembly SA

The figures[66] show that the level of automation of the Golf A5 SA has the best DRR with an average value of 78% on CP7, and the level of automation of the Auto5000 WOB has the best DRR with an average value of 94% on CP8. At both checkpoints the level of automation of the Golf A5 WOB has the worst DRR with an average value of 48% or rather 52%. These results can be explained by the above-mentioned reasons.

Process-Audit data

process steps in assembly product unit A5 Wolfsburg	
exteriour trim	88%
glass fitment	91%
battery	92%
total:	**93%**

process steps in assembly product unit Touran	
exteriour trim	90%
glass fitment	91%
battery	90%
total:	**89%**

process steps in assembly product unit A5 Uitenhage	
exteriour trim	87%
glass fitment	92%
battery	89%
total:	**90%**

Fig. 5.25: Process-Audit data of all assemblies[67]
Source: Own presentation

This figure shows the three tables of the three different assemblies. In these the total values of realisation degree as well as the values of realisation degree in the sub-

[64] See Appendix H29
[65] Details from Volkswagen AG Uitenhage, department Planning
[66] See Appendix H32-H35
[67] Details from Volkswagen AG Wolfsburg and Uitenhage, departments Quality

processes are described. It is problematic that the assembly processes do not exactly coordinate with the individual sub-processes of Process Audits. The sphere of assembly is included in the Process Audit[68].

As described above, because the sub-processes cannot be exactly coordinated with the Assembly Parts section, the total value, which refers to the whole assembly, is used. You can see that the level of automation of the Golf A5 WOB has the highest degree of realisation with 93%. The worst value of 89% is that of the level of automation of the Auto5000 WOB.

Summary of all quality values

All the above-determined values for the actual analysis of each production place are summarized in one matrix[69]. In this matrix these values are assessed as follows:

1. The ranking of all values are described as done above:
   Ranking in comparison to each other (best, second best and worst) is done.
2. Allocation of points to each status:
   Best gets 3 points, second best gets 2 points and worst gets 1 point.
3. Attaching importance to each value:
   The most convincing values are those of the assembly trouble cases[70]; they get the highest weight and are multiplied by the factor 3. All the other values[71] go down in assessment in single weight, in which the ranking, see above of DRR on CP7 as well as CP8 is assessed individually.
4. Sum of all points:
   The best existing level of automation has the most points.

The result is that according to the described determination, the level of automation of the Auto5000 WOB is actually the best with 35 points of all the other existing automation levels. Second best is the level of automation of the Golf A5 WOB with 31 points and third best is the level of automation of the Golf A5 SA with 24 points.

5.2.3 Determination of the optimal level of automation from a practical point of view

As can be seen in the matrixes of Assembly Parts[72], there are partly big differences in the number of trouble cases per vehicle with regard to the individual assembly steps. This is the reason for continuing with the investigation.

68 Details from Volkswagen AG Wolfsburg, department Quality
69 See Appendix H38
70 FISeQS- and My Process data
71 See Vehicle-Audit data, VPC, Field data, Direct-Runner-Rate data, Process-Audit data
72 See Appendix H14-H19

Now that this process has been investigated by actual analysis, it remains to find out if another fictitious level of automation applied to assembly trouble cases would deliver better values. With it is created in practical points of view in Assembly Part 1 and Assembly Part 2 each two more and in Assembly Part 3 four more levels of automation.

These levels of automation are created in the way described at the beginning of this chapter. So, two more levels of automation are created between the levels of automation of the Golf A5 WOB and the Auto5000 WOB in Assembly Part 1. A more fictitious subdivision is not useful for both practical and manufacture-orientated reasons. In the other two Assembly Parts[73,74] the created levels of automation are built up in the same way. With respect to Assembly Part 2 it has to be mentioned here that the fitting of the side windows in the level of automation of the Golf A5 SA is designed the same way as in the level of automation of the Auto5000 WOB for the reason already mentioned above.

This investigation is only feasible with the direct to individual assembly steps' assignable factors[75]. All other quality factors[76] can only be concluded from these results, because the data are assigned to the whole examined assembly area. But you can conclude that these quality values become better when defects in assembly are low. That is because the fewer defects occur the fewer defects have to be rectified and hence the values improve inevitably.

In these created levels of automation the assembly steps are now replaced with the trouble cases per vehicle as caused in these steps. Therefore, the number of trouble cases per vehicle is shown in the matrixes for each level of automation.

These results[77] show that the best result for all examined Assembly Parts is reached by a combination of already existing automation levels. This combination is that Assembly Part 1 has to be designed like the level of automation 3, Assembly Part 2 like the level of automation of the Auto5000 and Assembly Part 3 like the level of automation of the Golf A5 WOB.

5.2.4 Theoretical determination of the optimal level of automation

The closing part of this investigation is the determination of the optimal level of automation on a purely theoretical basis. Which step delivers the least trouble cases per vehicle in each Assembly Part is investigated here. These steps are summarized in one:

[73] See Appendix H40
[74] See Appendix H41
[75] FISeQS- and My Process data
[76] See Vehicle-Audit data, VPC, Field data, Direct-Runner-Rate data, Process-Audit data
[77] See Appendix H39-44

the theoretical optimal level of automation. In this level the way of assembly for the Assembly Part 1[78], Assembly Part 2[79] and Assembly Part 3[80] is shown theoretically, in order to find out where the fewest trouble cases occur.

These determined fields, including the trouble cases, are now replaced with the appropriate assembly steps, which caused them. Thus, it can be seen how the optimal automation level of each Assembly Part must be designed theoretically to produce the fewest trouble cases.

The results[81] of this investigation for every Assembly Part differ insignificantly from the determined levels of automation before.

5.2.5 Summary of the temporary results

In this part the temporary results are briefly summarized. The results of the actual analysis[82] show that the level of automation of the Auto5000 Wolfsburg manufactures best according to all analysed quality factors. Because of the clear differences in producing defects between the different levels of automation in assembly the investigation , according to this factor, is carried out from a practical point of view first and later from a purely theoretical point of view.

The results of the practical analysis[83] confirm the assumption that another level of automation will create fewer defects and describe that a combination of levels of automation will bring about a much better result than the existing levels of automation.

In the further theoretical investigation[84] the prior determined results are confirmed to a large extent. Only some differences are recognized but, in general, the trend is the same.

5.2.6 Assessment of credibility

Because all the results until now have provided information of the individual production places and are not self-determined, these have to be investigated with regard to their credibility and validity.

The production site in Wolfsburg has the Produktführerschaft concerning the Golf A5 as well as the Touran manufacture. Produktführerschaft means that this place of the production is the leader in the manufacture of this individual product. For this reason the

[78] See Appendix H45
[79] See Appendix H46
[80] See Appendix H47
[81] See Appendix H45-50
[82] See Appendix H38
[83] See Appendix H39-H44
[84] See Appendix H45-H50

control of the production site is particularly critical and thus the part of the Group. Therefore all examined stations are reproducible with the necessary standard of method competence. The production site in Uitenhage has no Produktführerschaft and so the following assessment has to be done.

Assessment of information about the Golf A5 manufacture in Uitenhage

The manufacture is located at a large distance from the headquarters of the VW Group. In the period of this investigation, in March 2006, the results of a vehicle Group Audit were published. In this Group Audit Group auditors rechecked vehicles which had already been checked by Volkswagen of South Africa over the period of three months.

The results of this Group-Audit[85] are compared to the results which VWSA made before. They were the following: the available quality result of the Group averages a Quality Class of 2.2 and the current result of VWSA averages a Quality Class of 1.6. If you look especially at the results of the Audit Points caused by assembly, the Group found out 244.3 points and in comparison VWSA found out 128.3 points. These results differ strongly from each other. This big difference has to be taken into consideration when examining the results. That is why an uncertainty factor is determined by the ratio of Audit Points. This uncertainty factor is 1.9 and it has to be included in all results, which are determined by the information from this production place.

Furthermore, it is apparent that the manufacture in Uitenhage does not fulfil the ergonomic and work-safety standards, which correspond to the manufactures of the Golf A5 and the Auto5000 in Wolfsburg. Moreover, the standard Quality Control in assembly is technologically methodical and in assessment not equally matched, so that there are imbalances in the results of the other existing production places.

- The incoming inspection of parts to be assembled is inadequately measured on the glaring defects
- Assembly of inferior quality parts causes high sequences of rework
- Assembly of changed parts exists without standardized fitted attempts in the special field
- Inadequately organized change of material regarding single-domination (tail light Golf A1, SBBR-Aufnahmeblech A5)
- Tools are not applicable for use (different torques are generated with a torque spanner or just with a ring spanner without control of torque in Golf A1 and A5 assembly)

[85] See Appendix I1

These experiences are made in the plant in Uitenhage in the period of this investigation. These events are not only seen in the Golf A5 assembly but also in the Golf A1 assembly. It is to recognize significantly that at the time of this determination the system of quality control does not fulfil its function. Standards are not comparable. Furthermore the features leadership and qualification of workers are not adequate.

This knowledge of missing bases, to which the production places of the Golf A5 and the Auto5000 are bound to by the above-mentioned reasons, has to be taken into consideration with the determined results.

5.2.7 Presentation of final results

The determined optimal level of automation for Assembly Part 1[86] corresponds to none of the existing automation levels. To reach this optimal level of automation, which will produce the fewest assembly defects, the Golf A5 assembly in Assembly Part 1 in Wolfsburg has to be de-automated. The Auto5000 assembly has to be automated to manufacture fewer faults. The same is valid for the Golf A5 assembly in Uitenhage, but first the above-mentioned deficits[87] have to be disposed of. As the optimal level of automation shows the prospective assembly in Assembly Part 1 has to be designed regarding quality aspects. Hence, there is a potential in the Golf A5 WOB assembly for de-automation, and in the Auto5000 as well as in the Golf A5 SA assembly there is a potential for automation.

For Assembly Part 2[88], the determined optimal level of automation reflects exactly the actual level of automation in the Auto5000 assembly. According to the results of this determination, the assembly of the Auto5000 is optimal in this Assembly Part. It means that the Golf A5 assembly has to be de-automated to reach this level and to produce fewer defects. The Golf A5 SA assembly has to be automated as a counter, but the above-mentioned points have priority. The prospective assembly in Assembly Part 2 has to be designed regarding quality aspects as the optimal level of automation shows. Hence, there is a potential for de-automation in the Golf A5 WOB assembly, and for automation in the Golf A5 SA assembly.

Unlike Assembly Part 2, Assembly Part 3[89] is exactly the level of automation of the Golf A5 WOB (is the determined) with the optimal level. It means that both the other existing levels of automation have to be automated to as high a level as already exists.

86 See Appendix I11
87 See 5.2.6
88 See Appendix I12
89 See Appendix I13

Here also, the creation of bases in the manufacture in Uitenhage has priority. The prospective assembly in Assembly Part 3 has to be designed regarding quality aspects as the optimal level of automation shows. Hence, there is a potential in the Auto5000 and the Golf A5 assembly for automation.

On the basis of these results it is clear that neither strict automation nor de-automation can be generalized as proven means from a qualitative point of view. Rather, the level of automation has to conform to the examined Assembly Parts including activities to manufacture optimally. This confirms the already mentioned results of the Fraunhofer Institut, in which more than one third of companies, after having had bad experiences with high automation, cut back their automation to conformist levels.

Conformist automation is the optimal precondition for faultless manufacture.

This is the end of the quality analyses. In the following chapter, the quantity aspect will be examined.

5.3 Examinations and results of quantity

Because of the different sizes and conditions of the examined production locations, the numbers of units cannot be the scale by which the locations can be compared. Every location has its own shift model and a different market demand. Hence, the quantitative aspects described before have to be considered.

The fundamentals for their calculation are shown in the following overview.

Locations		Golf A5 assembly line in Wolfsburg		
		Ass.part 1	Ass.part 2	Ass.part 3
Number of units	Scheduled	188564	210667	216927
	Actual	164713	164903	164412
Cycle time		1.361	1.379	1.371
Downtimes		203.1	148.9	184.4
Shift times		392		
Number of shifts		603		

Tab. 5.6: Production numbers Golf A5 assembly line in Wolfsburg
Source: Own presentation

Locations		Touran assembly line in Wolfsburg	Golf A5 assembly line in Uitenhage
Number of units	Scheduled	192240	41123
	Actual	185370	36019
Cycle time		1.476	6.407
Downtimes		169	163.4
Shift times		394	460
Number of shifts		720	523

Tab. 5.7: Production numbers Touran in Wolfsburg and Golf A5 assembly line in Uitenhage
Source: Own presentation

5.3.1 Calculation of quantitative aspects

Overall Equipment Effectiveness

First the Overall Equipment Effectiveness will be calculated; to calculate the OEE, the availability, speed and quality losses have to be calculated in single steps.

Golf A5 assembly line in Wolfsburg

Availability

Assembly Part 1:

$$t_{C1} = \frac{392\text{min} \cdot 603}{164713 + 8951} = 1{,}361\,\text{min} \tag{3}$$

t_{C1} = theoretical cycle time [min/unit]
t_{SH} = shift time [min]
n_A = actual number of units […]
n_L = number of lost units […]

$$t_B = \frac{1{,}361\,\text{min} \cdot 8951 \cdot 1\text{h}}{60\,\text{min}} = 203{,}1\text{h} \tag{4}$$

t_B = breakdown time [min]
t_{C1} = theoretical cycle time [min/unit]
n_L = number of lost units […]

Working hours: 3939,6h
Breakdown time: 203,1h

$$A_V = \frac{3939{,}6\text{h} - 203{,}1\text{h}}{3939{,}6\text{h}} \cdot 100\% = 94{,}84\% \tag{5}$$

A_V = availability [%]
t_W = working hours [h]
t_B = breakdown time [h]

Assembly Part 2:

$$t_{C1} = \frac{392\text{min} \cdot 603}{164903 + 6476} = 1{,}379\,\text{min} \tag{3}$$

$$t_B = \frac{1{,}379\,\text{min} \cdot 6476 \cdot 1\text{h}}{60\,\text{min}} = 148{,}9\text{h} \tag{4}$$

Breakdown time: 148,9h

$$A_V = \frac{3939{,}6\text{h} - 148{,}9\text{h}}{3939{,}6\text{h}} \cdot 100\% = 96{,}22\% \tag{5}$$

Assembly Part 3:

$$t_{C1} = \frac{392\text{min} \cdot 603}{164412 + 8047} = 1{,}371\,\text{min} \tag{3}$$

$$t_B = \frac{1{,}371\,\text{min} \cdot 8074 \cdot 1\text{h}}{60\,\text{min}} = 184{,}4\text{h} \tag{4}$$

Breakdown time: 184,4h

$$A_V = \frac{3939{,}6\text{h} - 184{,}4\text{h}}{3939{,}6\text{h}} \cdot 100\% = 95{,}32\% \tag{5}$$

Performance

Assembly Part 1:

Actual rate of production: 164713 units per year

Planned rate of production: 188564 units per year

$$S_R = \frac{164713}{188564} \cdot 100\% = 87{,}35\% \tag{8}$$

S_R = speed ratio [%]
n_A = actual number of units
n_P = planned number of units

Assembly Part 2:

Actual rate of production: 164903 units per year

Planned rate of production: 210667 units per year

$$S_R = \frac{164903}{210667} \cdot 100\% = 78{,}28\% \tag{8}$$

Assembly Part 3:

Actual rate of production: 164412 units per year

Planned rate of production: 216927 units per year

$$S_R = \frac{164412}{216927} \cdot 100\% = 75{,}79\% \tag{8}$$

The quality ratio is the quotient of good quality products and total products. This ratio corresponds to the direct runner rate. The direct runner rate is the same value for every Mechanisation because it is just documented at the end of the line. It varies between the different locations because every location has a different concept of putting the quality check to practice.

Quality

$$Q_R = 47{,}7\% \tag{9}$$

Q_R = quality ratio [%]

Overall Equipment Effectiveness

The overall equipment effectiveness is the product of all three factors.

Assembly Part 1:

Availability: 94,84%

Speed ratio: 87,35%

Quality ratio: 47,7%

Assembly Part 2:

Availability: 96,22%

Speed ratio: 78,28%

Quality ratio: 47,7%

Assembly Part 3:

Availability: 95,32%

Speed ratio: 75,79%

Quality ratio: 47,7%

The Assembly Parts are just parts of the entire assembly line. To compare the overall equipment effectiveness of the production locations an OEE of the Golf A5 line in Wolfsburg has to be calculated.

Therefore the availability is built of the entire working hours and the sum of the downtimes of the single Assembly Parts:

$$A_V = \frac{3939{,}6h - (203{,}1h + 148{,}9h + 184{,}4h)}{3939{,}6h} \cdot 100\% = 86{,}38\% \quad (5)$$

The speed ratio of the Golf A5 line in Wolfsburg is the average of the speed ratios of all three Assembly Parts:

$$S_R = \frac{87{,}35\% + 78{,}28\% + 75{,}79\%}{3} = 80{,}47\% \quad (8)$$

The quality ratio of all Assembly Parts is the same, because the quality is documented at the end of the line and not at the end of every Assembly Part:

$$Q_R = 47{,}7\% \quad (9)$$

$$OEE = 0{,}8638 \cdot 0{,}8047 \cdot 0{,}477 \cdot 100\% = 33{,}16\% \quad (10)$$

OEE = overall Equipment Effectiveness [%]
A_V = availability […]
S_R = speed ratio […]
Q_R = quality ratio […]

<u>Assembly line of the Auto5000 GmbH in Wolfsburg</u>

$$t_{C1} = \frac{394\min \cdot 720}{185370 + 6870} = 1{,}476\min \quad (3)$$

$$t_B = \frac{1{,}476\min \cdot 6870 \cdot 1h}{60\min} = 169h \quad (4)$$

Working hours: 4728h

Breakdown time: 169h

$$A_V = \frac{4728h - 169h}{4728h} \cdot 100\% = 96{,}43\% \quad (5)$$

Actual rate of production: 185370 units per year

Theoretical rate of production: 192240 units per year

$$S_R = \frac{185370}{192240} \cdot 100\% = 96{,}43\% \quad (8)$$

$$Q_R = 58{,}7\% \quad (9)$$

Overall Equipment Effectiveness

Availability: 96,43%

Speed ratio: 96,43%

Quality ratio: 58,7%

$$OEE = 0{,}9643 \cdot 0{,}9643 \cdot 0{,}587 \cdot 100\% = 54{,}58\% \quad (10)$$

<u>Golf A5 assembly line in Uitenhage</u>

$$t_{C1} = \frac{460\min \cdot 523}{36019 + 1530} = 6{,}407\min \quad (3)$$

$$t_B = \frac{6{,}407\min \cdot 1530 \cdot 1h}{60\min} = 163{,}4h \quad (4)$$

Working hours: 4009,7h

Breakdown time: 163,4h

$$A_V = \frac{4009{,}7h - 163{,}4h}{4009{,}7h} \cdot 100\% = 95{,}92\% \quad (5)$$

Actual rate of production: 36019 units per year

Planned rate of production: 41123 units per year

$$S_R = \frac{36019}{41123} \cdot 100\% = 87{,}59\% \quad (8)$$

$$Q_R = 77{,}8\% \quad (9)$$

Overall Equipment Effectiveness

Availability: 95,92%

Speed ratio: 87,59%

Quality ratio: 77,8%

$$OEE = 0{,}9592 \cdot 0{,}8759 \cdot 0{,}778 \cdot 100\% = 65{,}36\% \quad (10)$$

5.3.2 Indexes of productivity

The indexes of productivity are calculated by some of the numbers, which were used to calculate the OEE. The numbers of employees are also considered.

Golf A5 assembly line in Wolfsburg

In the year 2005 164,412 vehicles were built at the assembly line 3 in Wolfsburg. In the chosen operations 23 employees per shift worked on those vehicles in 603 shifts with a net working time of 392 minutes each.

This leads to the working hours of every employee and the total working time of all employees:

$$t_W = n_S \cdot t_{SH} = \frac{603 \cdot 392\text{min} \cdot 1\text{h}}{60\text{min}} = 3939{,}6\text{h} \quad (26)$$

t_W = working hours [h]
n_S = number of shifts […]
t_{SH} = shift time [min]

$$t_{WE} = t_W \cdot n_E = 3939{,}6\text{h} \cdot 23 = 90610{,}8\text{h} \quad (27)$$

t_{WE} = working hours of all employees [h]
t_W = working hours [h]
n_E = number of employees […]

The index of productivity “Vehicles per employee” will be calculated next by dividing the number of units by the number of employees:

$$n_V = \frac{n_A}{n_E} = \frac{164412}{23} = 7148{,}35 \quad (28)$$

n_V = vehicles per employee
n_A = actual number of units
n_E = number of employees

One of many other indexes is “Vehicles per worker’s hours”. This index is calculated by the number of units and the working hours of all employees:

$$n_H = \frac{n_A}{t_{WE}} = \frac{164412}{90610{,}8\text{h}} = 1{,}81\tfrac{1}{\text{h}} \quad (29)$$

n_H = vehicle per worker’s hour
n_A = actual number of units
t_{WE} = working hours of all employees [h]

Touran assembly line Auto5000 GmbH in Wolfsburg

The Auto5000 GmbH manufactured 185,370 Tourans in the year 2005. 46 employees per shift executed the chosen operations in 720 shifts with a net working time of 394 minutes each.

With these values the working hours per employee and the working hours of all employees can be calculated:

$$t_W = \frac{720 \cdot 394\text{min} \cdot 1\text{h}}{60\text{min}} = 4728{,}0\text{h} \tag{26}$$

$$t_{WE} = 4728\text{h} \cdot 46 = 217488\text{h} \tag{27}$$

The next step is the calculation of the vehicles every worker built on average:

$$n_V = \frac{n_A}{n_E} = \frac{185370}{46} = 4029{,}8 \tag{28}$$

n_V = vehicles per employee
n_A = actual number of units
n_E = number of employees

The number of units and the working hours of all employees will calculate the vehicles per worker's hour as follows:

$$n_H = \frac{n_A}{t_{WE}} = \frac{185370}{217488\text{h}} = 0{,}85\tfrac{1}{\text{h}} \tag{29}$$

n_H = vehicle per worker's hour
n_A = actual number of units
t_{WE} = working hours of all employees [h]

<u>Golf A5 assembly line in Uitenhage</u>

In South Africa 36,019 vehicles of the A5 platform left the assembly line in the year 2005. Each of the 523 shifts had 460 minutes net working time and 30 employees worked on average.

$$t_W = \frac{523 \cdot 460\text{min} \cdot 1\text{h}}{60\ \text{min}} = 4009{,}7\text{h} \tag{26}$$

$$t_{WE} = 4009{,}7\text{h} \cdot 30 = 120290\text{h} \tag{27}$$

The average number of vehicles manufactured by every worker is:

$$n_V = \frac{n_A}{n_E} = \frac{36019}{30} = 1200{,}63 \tag{28}$$

n_V = vehicles per employee
n_A = actual number of units
n_E = number of employees

Vehicles per worker's hour will be calculated in the following figure by the number of units and the working hours of all employees:

$$n_H = \frac{n_A}{t_{WE}} = \frac{36019}{120290\ \text{h}} = 0{,}30\tfrac{1}{\text{h}} \tag{29}$$

n_H = vehicle per worker's hour
n_A = actual number of units
t_{WE} = working hours of all employees [h]

These results are shown in the following table.

Productivity			
Locations	Golf A5 assembly line in Wolfsburg	Touran assembly line in Wolfsburg	Golf A5 assembly line in Uitenhage
Number of units	164412	185370	36019
Number of employees	23	46	30
Number of shifts	603	720	523
Shift time in min	392	394	460
Working hours per employee	3939,6	4728	4009,7
Working hours of all employees	90610,8	217488	120290
Vehicles per worker's hour	**1,81**	**0,85**	**0,3**
Vehicles per employee	**7148,35**	**4029,8**	**1200,63**

Tab. 5.8: Productivity
Source: Own presentation

5.3.3 Evaluation

The overall equipment effectiveness and its components of the production locations are shown in the following figures.

Availability:

Golf A5 assembly line in Wolfsburg 86.40%

Touran assembly line of the Auto5000 GmbH in Wolfsburg 96.43%

Golf A5 assembly line in Uitenhage 95.92%

In this comparison the availability is obviously the lowest in the Golf A5 assembly line in Wolfsburg. This result can be explained with the high automation degree in Wolfsburg. Machines have a bigger potential of standstill losses. And exactly this can be seen as one of the biggest disadvantages of a high-automated production.

Speed ratio:

Golf A5 assembly line in Wolfsburg 80.47%

Touran assembly line of the Auto5000 GmbH in Wolfsburg 96.43%

Golf A5 assembly line in Uitenhage 87.59%

The speed ratio is different because of the different shift models. The Touran assembly line is on top because an extra shift will take place on Saturday if the scheduled number of units cannot be reached on Friday. Because of that the Auto 5000 GmbH is closest to its target regarding the number of units.

Quality ratio:

Golf A5 assembly line in Wolfsburg 47.70%

Touran assembly line of the Auto5000 GmbH in Wolfsburg 58.70%

Golf A5 assembly line in Uitenhage 77.80%

The differences between the quality ratios and, therefore, the direct runner rates are caused by the different rework models. In Uitenhage rework already takes place at the line and so the quality ratio is at a high level. At the Golf A5 assembly line in Wolfsburg the rework takes place after the checkpoint, hence the quality ratio is the lowest in comparison.

Overall equipment effectiveness:

Golf A5 assembly line in Wolfsburg	33.16%
Touran assembly line of the Auto5000 GmbH in Wolfsburg	54.58%
Golf A5 assembly line in Uitenhage	65.36%

The overall equipment effectiveness can be seen as a summary of the availability, speed and quality, and shows a result of those three factors.

Vehicles per employee:

Golf A5 assembly line in Wolfsburg	7148.4
Touran assembly line of the Auto5000 GmbH in Wolfsburg	4029.8
Golf A5 assembly line in Uitenhage	1200.6

Vehicles per worker's hour:

Golf A5 assembly line in Wolfsburg	1.81
Auto 5000 GmbH	0.85
Golf A5 assembly line in Uitenhage	0.30

The index "vehicles per employee" shows that in the Golf A5 assembly line in Wolfsburg the smallest number of employees is needed to manufacture a vehicle or rather one employee manufactures the most vehicles in a comparison of the three locations. The index "vehicles per worker's hour" shows nearly the same result but also considers the shift model and net working time.

5.3.4 Analysis

Preconditions

In this part the production locations are compared to their flexibility towards the changing number of pieces. Therefore, it is assumed that every manufacturing would have had to produce 20 % more and 20 % fewer vehicles.

This assumption is made for every Assembly Part at every location for all possible levels of automation. The number of workers, who participated in the production process of the examined areas will be calculated by the matrixes and the assumed cycle times. Then a productivity analysis will be made with the key numbers of productivity specified before. To calculate the vehicles per employee the assumed number of units produced will be divided by the number of workers required in the examined fields. The key number vehicles per worker's hour will also consider the shift model.

Calculation

The calculation with a varying number of units will identify how flexible the different automation strategies are. From this point of view, production is the most flexible, which changes the least to cope with different conditions. Another criterion is productivity. So the order of criteria in this analysis is:

1. The number of participated workers: this number has to be constant
2. The level of automation: in the best case nothing has to be changed
3. The productivity: the best value has to be reached.

Golf A5 assembly line in Wolfsburg

In Assembly Part 1, the actual number of units is 164,713. To produce this number of units a cycle time of 1.4350 minutes on average is necessary. The assumed numbers of units are ±20%. That means that in one case 131,770 vehicles have to be built with a cycle time of 1.7938 minutes and in the other case 197,655 vehicles with a cycle of 1.1959 minutes. In this overview you can see that in the Assembly Part 1 of the Golf A5 assembly line in Wolfsburg there is only a difference of 2 workers in level 1 to react to the changed numbers of units. Furthermore, the productivity of this level is the highest in this comparison.

Level	Workers	Vehicles per worker	Vehicles per worker's hour
1	9	18301	4,65
2	11	14973	3,80
3	14	11765	2,99
4	19	8669	2,20
5	22	7487	1,90
"+20%"			
1	10	19766	5,02
2	13	15204	3,86
3	18	10981	2,79
4	25	7906	2,01
5	28	7059	1,79
"-20%"			
1	8	16471	4,18
2	10	13177	3,34
3	14	9412	2,39
4	19	6935	1,76
5	19	6935	1,76

Tab. 5.9: Analysis Golf A5 Assembly Part 1 in Wolfsburg
Source: Own presentation

In Assembly Part 2 of the Golf A5 assembly line in Wolfsburg 164,903 vehicles were built with a cycle time of 1.4334 minutes on average in 2005. The changed conditions are to build 197,883 vehicles and 131,922 vehicles with cycle times of 1.1945 minutes and 1.7918 minutes respectively. This overview shows that in the Assembly Part 1 of the Golf A5 line in Wolfsburg level 1 only has a difference of 2 workers to handle the changed numbers of units. And the productivity at this level is the highest in this comparison. Additionally, it has to be said that nothing has to be changed on the assembly line.

Level	Workers	Vehicles per worker	Vehicles per worker's hour
1	8	20613	5,23
2	10	16490	4,19
3	11	14991	3,81
4	12	13742	3,49
5	42	3926	1,00
"+20%"			
1	9	21987	5,58
2	12	16490	4,19
3	14	14135	3,59
4	14	14135	3,59
5	48	4123	1,05
"-20%"			
1	7	18846	4,78
2	10	13192	3,35
3	10	13192	3,35
4	9	14658	3,72
5	34	3880	0,98

Tab. 5.10: Analysis Golf A5 Assembly Part 2 in Wolfsburg
Source: Own presentation

Level	Workers	Vehicles per worker	Vehicles per worker's hour
1	6	27402	6,96
2	8	20552	5,22
3	8	20552	5,22
4	8	20552	5,22
5	13	12647	3,21
6	17	9671	2,45
7	20	8221	2,09
"+20%"			
1	6	32882	8,35
2	8	24662	6,26
3	10	19729	5,01
4	8	24662	6,26
5	14	14092	3,58
6	18	10961	2,78
7	23	8578	2,18
"-20%"			
1	6	21922	5,56
2	6	21922	5,56
3	8	16441	4,17
4	8	16441	4,17
5	13	10118	2,57
6	15	8769	2,23
7	18	7307	1,85

Tab. 5.11: Analysis Golf A5 Assembly Part 3 in Wolfsburg
Source: Own presentation

In Assembly Part 3 of the Golf A5 assembly line in Wolfsburg 164,412 vehicles were built with a cycle time of 1.4377 minutes on average in 2005. The changed conditions are to build 197,294 vehicles and 131,529 vehicles with cycle times of 1.1980 minutes and 1.7971 minutes respectively.

The levels 1 and 4 do not need changes in the number of workers to change their number of produced units, so these are the most flexible ones in this comparison. But level 1 demonstrates a better productivity, hence level 1 is the best from the quantity's point of view. And in this part of the assembly too, nothing has to be changed to react to the changed demands.

At the end of the analysis of the Golf A5 assembly line in Wolfsburg level 1 is the optimal level for varying the number of units.

Touran assembly line Auto5000 GmbH in Wolfsburg

The Touran assembly built 185,370 vehicles in 2005. This recommended an average cycle time of 1.5303 minutes. If it had been demanded to increase production by 20%, or 222,444 vehicles, the cycle time would have been 1.2753 minutes. Alternatively, with a decrease in production of 20%, or 148,296 vehicles in 720 shifts with a net shift time of 396 minutes each the cycle time would have reached an average of 1.9129 minutes.

Level	Workers	Vehicles per worker	Vehicles per worker's hour
1	9	20597	4,36
2	11	16852	3,56
3	14	13241	2,80
4	19	9756	2,06
5	21	8827	1,87
"+20%"			
1	10	22244	4,70
2	12	18537	3,92
3	16	13903	2,94
4	23	9671	2,05
5	25	8898	1,88
"-20%"			
1	8	18537	3,92
2	10	14830	3,14
3	13	11407	2,41
4	18	8239	1,74
5	18	8239	1,74

Tab. 5.12: Analysis Touran Assembly Part 1 in Wolfsburg
Source: Own presentation

In Assembly Part 1 this result shows that the actual level of automation of the Touran assembly is not the most flexible to the changing numbers of units in the examined operations. It also shows that the automation degree has to be increased to be more flexible.

Both level 1 and level 2 show the same flexibility. Level 1 is more productive but the assembly has to be changed less to change to level 2.

In Assembly Part 2, the result of Assembly Part 2 of the Auto 5000 GmbH is that the participated workers in the examined fields have to be changed least in levels 2 and 3. Towards an increasing number of units the actual level of the Touran assembly is nearly optimallly designed. The productivity of levels 2 and 3 is the same, so the level 3 is the best in this comparison because, as seen before, the changes in the number of workers are the least and the changes in the assembly are less than if changed to automation level 2.

Level	Workers	Vehicles per worker	Vehicles per worker's hour
1	8	23171	4,90
2	10	18537	3,92
3	10	18537	3,92
4	10	18537	3,92
5	39	4753	1,01
"+20%"			
1	9	24716	5,23
2	11	20222	4,28
3	11	20222	4,28
4	11	20222	4,28
5	45	4943	1,05
"-20%"			
1	7	21185	4,48
2	10	14830	3,14
3	10	14830	3,14
4	9	16477	3,49
5	32	4634	0,98

Tab. 5.13: Analysis Touran Assembly Part 2 in Wolfsburg
Source: Own presentation

Level	Workers	Vehicles per worker	Vehicles per worker's hour
1	6	30895	6,53
2	8	23171	4,90
3	8	23171	4,90
4	8	23171	4,90
5	14	13241	2,80
6	17	10904	2,31
7	20	9269	1,96
"+20%"			
1	6	37074	7,84
2	8	27806	5,88
3	8	27806	5,88
4	8	27806	5,88
5	14	15886	3,36
6	18	12358	2,61
7	23	9671	2,05
"-20%"			
1	6	24716	5,23
2	6	24716	5,23
3	8	18537	3,92
4	8	18537	3,92
5	12	12358	2,61
6	15	9886	2,09
7	18	8239	1,74

Tab. 5.14: Analysis Touran Assembly Part 3 in Wolfsburg
Source: Own presentation

In Assembly Part 3 the third fictitious level of automation, level 4, is the most flexible level towards the changing number of units with the lowest demand of changes in the line. Nevertheless, level 1 shows the same changes of the number of workers with a higher productivity, because fewer workers participate in the production process.

Golf A5 assembly line in Uitenhage

In South Africa 36,019 vehicles of the A5 platform were produced in 2005. The cycle time to produce this number of units is 6.6793 minutes on average. If 20% more vehicles had been built, or 43,222 vehicles, the cycle time would have been 5.566 minutes. In the case of 20% less vehicles, or 28,815 vehicles, the average cycle time of 8.3491 minutes would have been necessary.

Level	Workers	Vehicles per worker	Vehicles per worker's hour
1	5	7204	1,80
2	6	6003	1,50
3	8	4502	1,12
4	10	3602	0,90
5	9	4002	1,00
"+20%"			
1	5	8644	2,16
2	6	7204	1,80
3	8	5403	1,35
4	10	4322	1,08
5	9	4802	1,20
"-20%"			
1	4	7204	1,80
2	6	4803	1,20
3	8	3602	0,90
4	10	2882	0,72
5	8	3602	0,90

Tab. 5.15: Analysis Golf A5 Assembly Part 1 in Uitenhage
Source: Own presentation

In Assembly Part 1, the most flexible automation levels are the levels 2, 3 and 4. Thereby level 2 shows the best productivity of these three levels. But changing from level 5 to level 4 needs the least changes in the assembly line.

Level	Workers	Vehicles per worker	Vehicles per worker's hour
1	4	9005	2,25
2	6	6003	1,50
3	8	4502	1,12
4	7	5146	1,28
5	12	3002	0,75
"+20%"			
1	4	10806	2,69
2	6	7204	1,80
3	8	5403	1,35
4	7	6175	1,54
5	14	3087	0,77
"-20%"			
1	4	7204	1,80
2	6	4803	1,20
3	8	3602	0,90
4	7	4116	1,03
5	11	2620	0,65

Tab. 5.16: Analysis Golf A5 Assembly Part 2 in Uitenhage
Source: Own presentation

In Assembly Part 2, the levels 1 to 4 do not require any changes in the number of participating employees to cope with a change of number of units in the examined range. On the one hand level 1 represents the level with the highest productivity, but, on the other hand, level 4 is the level with the lowest changing demand.

In Assembly Part 3, the result of the Assembly Part 3 in Uitenhage shows a quite similar result like the other Assembly Part in South Africa. Levels 1 to 6 provide the same flexibility and level 1 is the most productive of the compared levels. The productivity increases with the degree of automation.

Level	Workers	Vehicles per worker	Vehicles per worker's hour
1	4	9005	2,25
2	5	7204	1,80
3	7	5146	1,28
4	7	5146	1,28
5	9	4002	1,00
6	9	4002	1,00
7	9	4002	1,00
"+20%"			
1	4	10806	2,69
2	5	8644	2,16
3	7	6175	1,54
4	7	6175	1,54
5	9	4802	1,20
6	9	4802	1,20
7	10	4322	1,08
"-20%"			
1	4	7204	1,80
2	5	5763	1,44
3	7	4116	1,03
4	7	4116	1,03
5	9	3202	0,80
6	9	3202	0,80
7	9	3202	0,80

Tab. 5.17: Analysis Golf A5 Assembly Part 3 in Uitenhage
Source: Own presentation

6. Combination of the results

This chapter deals with the combination of the results of the three areas costs, quality and quantity. Before the analyses of these areas can be carried out the same basis for the examined area has to be guaranteed for all production sites. The creation of the same basis and the following analyses of the three areas have been done in Ch. 5 already. After showing in the following paragraphs how the same basis has been created, initial situations and actual problems of each production site are explained and confronted. After that, the combination of the areas can be set up to find the total optimal levels of automation for each production site.

Starting points of the analyses were the 3 Mechanisations of the assembly line in Wolfsburg. In each Mechanisation certain stations have been selected, which form the so-called Assembly Parts 1, 2 and 3. These are a reference for both of the other productions sites. All the stations of equivalent content were compared with the stations of Assembly Parts 1, 2 and 3. This procedure was necessary for creating different levels of automation. By examining the 3 different assembly lines, up to 3 different possible ways of assembling a certain component could be differentiated. For each Assembly Part different levels of automation have been created in matrixes with the help of the possible ways of assembling. Each Assembly Part got its own matrix. All of them are shown in **Appendix C1-C3**. In each line of the matrixes, the different levels of automation are shown as in Fig. 6.1 on the following page. As already mentioned, the starting point of creating different levels of automation is the way, in which the Golf A5 is assembled in Wolfsburg. Therefore, the first level of automation represents the way in which the Golf A5 is assembled in Wolfsburg. With the growing number of levels from top to bottom, the level of automation decreases. For each further level the most meaningful important stations regarding costs are deautomated. The last level of automation always represents the way in which the Golf A5 is assembled in Uitenhage in practice.[1] This level shows the least

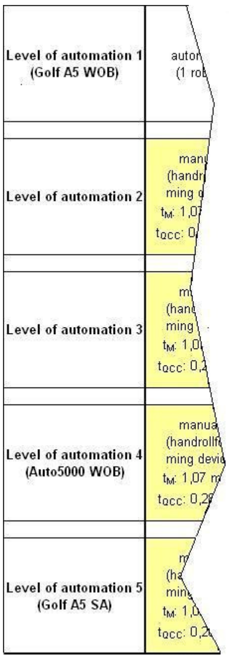

Fig. 6.1 Example for levels of automation
Source: Own presentation

[1] Levels, which represent assembling in practise: Level 5 in Assembly Part 1 and 2, level 7 in Assembly Part 3

automated way of assembling. In between, there is one level of automation that represents how the Touran in the Auto5000 GmbH is assembled in practice.[2] Depending on the stations the 3 matrixes of Assembly Parts 1, 2 and 3 have a different number of levels of automations (5, 5, 7 levels).

The examination of costs takes into consideration the costs for personnel[3] and automation costs[4]. For the determination of quality assembly defects[5], Vehicle-Audit data, data of the Vehicle Preparation Centre in Japan, Field-data, Direct-Runner-Rate data, Process-Audit data as well as the qualification and co-ordination of workers are considered. The quantity investigation is mainly based on the productivity[6] and flexibility[7]. Furthermore, the overall equipment effectiveness is examined.

On the following page, an overview of initial situations of each production site is presented to show in detail which kinds of challenges or rather problems actually exist in practice. These mentioned situations are explained in detail in the following chapters.

The combination of each result bases on the results of costs. Therefore, the actual and optimal levels of automation regarding costs are also represented on the following page in Fig. 6.2 to Fig. 6.10 to show an overview regarding the differences between optimal and actual level of automation according to costs before beginning the combination in Ch. 6.1.

[2] Levels, which represent assembling in practise: Level 4 in Assembly Part 1 and 2, level 6 in Assembly Part 3
[3] See 5.1.1: Direct workers, master, maintenance, planning and industrial engineering
[4] See 5.1.1: Capital investment, energy costs, equipment for maintenance use and operating supplies
[5] See 5.2.1: Investigated from the systems FISeQS (Golf Wob), My Process (Auto5000) and FISview (Golf SA) and later used for the determination of the optimal level regarding quality
[6] See 5.3.2: Calculated by the number of unit, number of workers and working hours
[7] See 5.3.4: Describes the necessary changes of workers to varying number of units

Golf A5 assembly in Wolfsburg

High automation:
- Low demand for man-power
- High maintenance effort
- Not quality supplying (no tolerance compensation by robots)
- Over-dimensioning of Mechanisations are necessary to balance interruptions

Crowd of employees and decreasing number of produced units:
- Plant production volume decreases from 6,000 to only 2,000 units per day on two assembly lines
- Capacity utilisation of the automation does not exist anymore
- Employees have to be employed in other areas
- Loss of know-how

Very high wage costs:
- VW collective agreement
- Working hours are inflexible

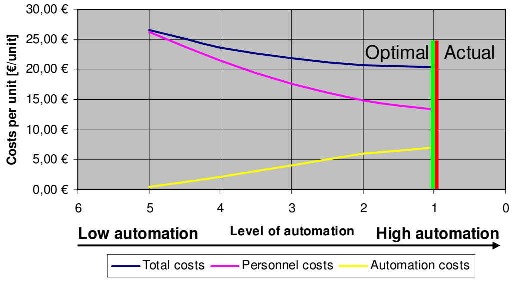

Fig. 6.2: Costs per unit (Assembly Part 1)
Source: Own presentation

Fig. 6.3: Costs per unit (Assembly Part 2)
Source: Own presentation

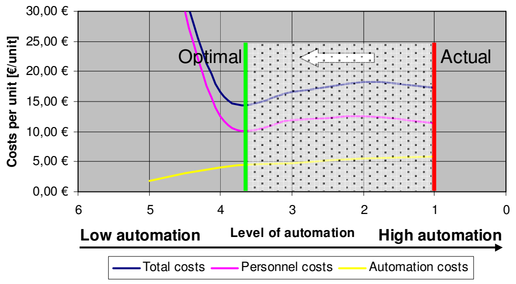

Fig. 6.4: Costs per unit (Assembly Part 3)
Source: Own presentation

Auto5000 assembly in Wolfsburg

Low automation:
- Example for adapted automation
- Increasing demand on man-power
- Low maintenance effort
- Quality supplying (tolerance compensation by workers)
- Main field on worker qualification and leadership

Produced number of units:
- 801 produced units per day on one assembly line
- Good capacity utilisation of manufacture
- Additional assembling of the new vehicle Tiguan on the Touran assembly line
- Flexible extension of the assembly line

Conformist wage costs:
- Special Auto5000 collective wage
- Flexible working hours to catch up interruptions

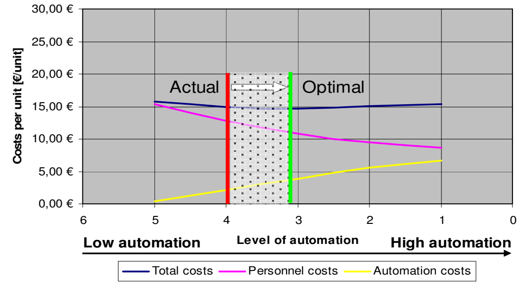

Fig. 6.5: Costs per unit (Assembly Part 1)
Source: Own presentation

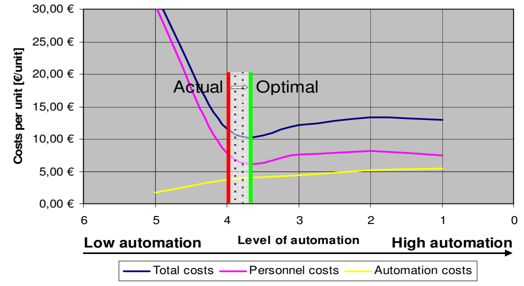

Fig. 6.6: Costs per unit (Assembly Part 2)
Source: Own presentation

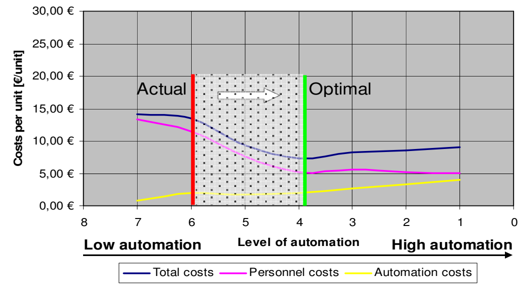

Fig. 6.7: Costs per unit (Assembly Part 3)
Source: Own presentation

Golf A5 assembly in Uitenhage

No automation:
- Manual manufacture
- High demand for man-power
- Very low maintenance effort
- Improvement in workers' qualification and leadership

Produced number of units:
- 144 produced units per day on one assembly line
- Very high circle time (ø-circle time 4,55 min)
- A lot of space for increasing numbers of units

Low wage costs:
- Very low collective wages
- Additional work on Saturdays to reach production targets

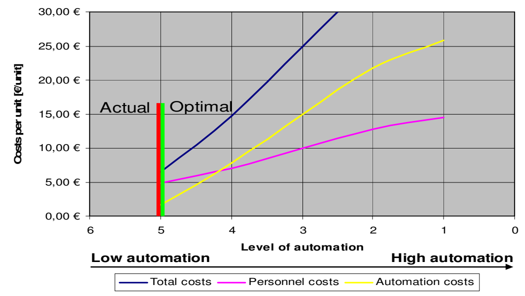

Fig. 6.8: Costs per unit (Assembly Part 1)
Source: Own presentation

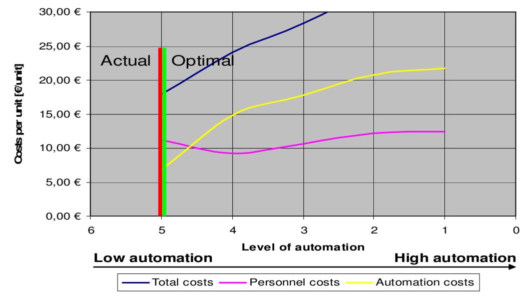

Fig. 6.9: Costs per unit (Assembly Part 2)
Source: Own presentation

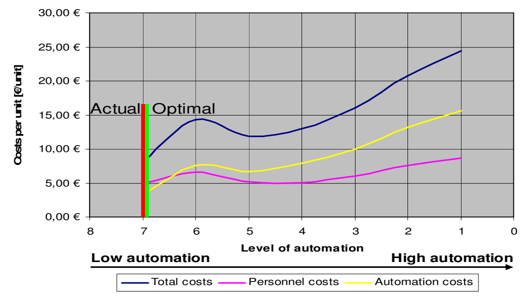

Fig. 6.10: Costs per unit (Assembly Part 3)
Source: Own presentation

Fig. 6.2 - Fig. 6.10 represent the costs per unit for each Assembly Part in each production site versus the level of automation (3 figures for each production site). The total costs per unit (coloured blue) are subdivided into personnel costs (coloured red) and into automation costs (coloured yellow). Therefore, the total costs per unit are calculated by adding up the personnel and automation costs per unit. On the X-axis, level 0 represents full automation (100%). Level 6 or rather level 8 represents fully-manual assembling (0%). In each figure, the existing level of automation (red coloured bars) is shown in practice as well as the determined optimal level regarding cost (green coloured bars) in Ch. 5.1.

In Assembly Part 1 in the Golf A5 assembly line in Wolfsburg, the actual level confirms the optimal level. But, in Assembly Part 2 and 3, the optimal levels are near to level 4 while levels 1 represent the actual levels. Because of smaller demand of man-power, the personnel costs decrease with increasing automation. In contrast to this, highly automated facilities and high maintenance effort cause increasing automation costs.

The assembly line of the Auto5000 GmbH is an example of adapted automation, which leads to low automated assembling. But, as can be seen in Fig. 6.5 - Fig. 6.7, the investigations have shown that a little more automation leads to cost optimal assembling in all Assembly Parts. The adapted automation causes an increase in man-power whereas the costs for automation decrease, especially costs for facilities and maintenance.

In the assembly line of the Golf A5 in Uitenhage, the actual levels of automation confirm the determined optimal levels. The low wage costs in South Africa and the small number of units cause a strong increase of costs per unit with increasing automation.

These determined costs show some discrepancies to the theoretical costs, already shown in Fig. 4.6 and again in Fig. 6.11. The reasons for the differences of the courses between the theoretical courses of the costs per unit and the determined costs per unit, as shown in Fig. 6.2 - Fig. 6.10, are caused by:

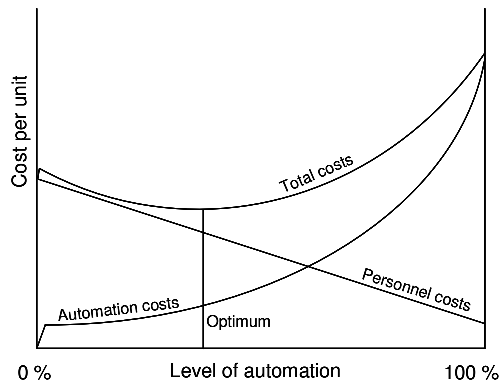

Fig. 6.11: Costs per unit vs. level of automation
Source: Fichtmüller 1996, p. 7

- Personnel costs in Fig. 6.11 only include direct workers, but in Fig. 6.2 - Fig. 6.10, these costs include direct workers as well as indirect workers (master, maintenance, planning and industrial engineering)

- Uniform scaling of the y-axes in Fig. 6.2 - Fig. 6.10, which enables a comparison of the costs per unit among all production sites. Therefore, some curve progressions are distorted.
- Linear scaling of the levels of automation on the x-axis in Fig. 6.2 - Fig. 6.10, however, in reality the ranges between the different levels are not absolutely linear.

In the next chapter, the optimal levels of automation of the three aspects costs, quality and quantity are confronted with each other. If the different optima correspond to each other, the total optimum for the individual Assembly Part is already founded. Otherwise, if the optima show differences in a certain Assembly Part, further contemplations have to be carried out. In the combination of the optima, the optimal levels of costs are defined as the basis. Both of the other aspects are confronted with the optimal level of costs to find a total solution for each production site. The results will give recommendations for each production site in order to guarantee optimal kinds of assembling.

6.1 Combination of the results of Golf A5 assembly in Wolfsburg

In this chapter the results of costs, quality and quantity of the Golf A5 assembly in Wolfsburg are combined with each other. The next chapter will give an overview of the individual optimal levels of automation. Then, in Ch. 6.1.2, the total optimal level of automation will be determined.

6.1.1 Confronting the optimal levels of automation

The individual results of the three aspects cost, quality and quantity are shown in Tab. 6.1, which represents the optimal levels of automation for each aspect in each Assembly Part of the Golf A5 assembly in Wolfsburg. Furthermore, the values, which belong to the optimal levels, are shown in this table.

As can be seen, in Assembly Part 1 the first level is the optimal level according to costs

Golf A5 WOB Assembly Part 1			
Aspects	**Level of automation**		
	Optimal (value)		**Actual**
Costs	1	(20,38 €)	1
Quality	3	(0,01988 T.C./veh.)	
Quantity	1	(4,65 veh./h.)	

Golf A5 WOB Assembly Part 2			
Aspects	**Level of automation**		
	Optimal (value)		**Actual**
Costs	4	(16,60 €)	1
Quality	4	(0,02330 T.C./veh.)	
Quantity	1	(5,23 veh./h.)	

Golf A5 WOB Assembly Part 3			
Aspects	**Level of automation**		
	Optimal (value)		**Actual**
Costs	4	(10,64 €)	1
Quality	1	(0,00737 T.C./veh.)	
Quantity	1	(6,96 veh./h.)	

Tab. 6.1: Optimal levels of automation regarding costs in the three Assembly Part of Golf A5 manufacture in Wolfsburg
Source: Own presentation

and quantity. The results of quality deliver the third level as the optimal level. In Assembly Part 2, level four is optimal for cost and quality. As in Assembly Part 1, the first level represents the optimum for quantity. The fourth level is also the optimum regarding cost in Assembly Part 3, but with regard to quality and quantity the first level is the optimal level. In the following chapter, the mentioned differences will be discussed to a total solution.

6.1.2 Determination of the total optimal level of automation

The optimal levels of cost are defined as the bases. In Assembly Part 1, the first level of automation is the optimal level, which represents actual assembling in practice. The result of quantity shows the same optimum, which causes no adaptation. But the result of quality has to be taken into closer consideration. The differences[8] between the first and the third level of automation are 0.005 trouble cases per vehicle from a quality point of view. This means that the first level of automation causes 0.005 trouble cases per vehicle, which is more than the third level on average. A more detailed examination illustrates that only the assembly stations roll-forming tailgate as well as roll-forming doors cause this difference.

This fact is a very good example for the area of conflicts between quality, flexibility and know-how (see Fig. 6.12).

Fig. 6.12: Area of conflicts
Source: Own presentation

An automatic station/robot allows only a very small tolerance for assembling. For a high-quality manufacture it is essential that the size of the body always has to move into the limits of these tolerances. If this tolerance is gone over, the robot is not able to react appropriately, because an automatic station is not flexible enough to compensate abrupt variances of tolerances. The above-mentioned example of the manufacturing station roll-forming illustrates this fact.

The determination of cost of this Assembly Part states the first level as the optimal level. So, the differences between the optimal level of costs and quality have to be remedied. To reach a better quality in this cost optimal level, an improvement of know how has to be done in the automatic assembly of roll-forming. This can be

[8] See Appendix H42

reached by a better quality or a rather smaller range of tolerance of products handed over from previous areas. Furthermore, an improvement of the adjustment of the robot, a more appropriate maintenance of the robot or a further development of the roll-forming tool for robots could increase the quality.

Hence, the know how of the automatic station has to be increased to equalise the mentioned inflexibility of such stations. Hence, in this Assembly Part the optimal level of automation regarding quality corresponds to the optimal level of automation regarding costs.

For Assembly Part 1, the optimum in quantitative aspects is level 1. Because of the high level of automation of level 1 the productivity is very high. Level 1 is very flexible. Only small changes in the number of workers are necessary to react on a varied number of units.

In Assembly Part 2, the determination of the optimal level of costs and quality deliver the same level of automation as the optimal. This illustrates that the assembly of the examined station in Assembly Part 2 regarding cost and quality is optimally designed, but the actual level of automation is level 1. The optimal level of automation for Assembly Part 2 in quantitative aspects is level 1. According to flexibility the levels 1 and 2 demonstrate the best possibility of reacting on market fluctuations. But level 4 shows a rising productivity to decreasing number of units. Additionally, it provides a better technical availability than the high-automated levels. The discussions show that there is potential to deautomate this Assembly Part in the Golf A5 manufacture in Wolfsburg.

As in the beginning of this part, the results of costs and quality are also different from each other in Assembly Part 3. To reach an optimal quality in the level of automation 4, which represents the optimal level regarding costs, the quality results have to be taken into closer consideration. By analysing in detail, the quality differences[9] of 0.021 trouble cases per vehicle are caused by the assembly stations fitting and putting in battery as well as fitting cross member and rear bumper. The assembly is performed automatically with a better quality than manually in these stations. In the other Assembly Parts, manual assembly produces as well as robots, in certain stations even better. This illustrates the possibilities of manual assembly. But, for reaching a high-quality performance in manual assembly workers have to be adequately qualified, motivated and co-ordinated. In the above-mentioned assembly stations

[9] See Appendix H44

workers could assemble as well as the robots unless the workers have the appropriate Know How. This could be reached by putting the main field on workers qualification, motivation and leadership. The putting into practice of the mentioned modifications will lead to a quality improvement. So, the optimal level of automation regarding quality corresponds to the optimal level of automation regarding costs. The quantity aspect shows that levels 1 and 4 provide the best flexibility. Level 1 shows a better productivity because of its high automation degree. The other possibility, level 4, which is preferred from the point of view of costs, has the same flexibility as level 1. But, level 4 provides a better technical availability because of its lower automated way of manufacturing.

6.2 Combination of the results of Auto5000 assembly in Wolfsburg

6.2.1 Confrontation of the optimal levels of automation

The individual results of the three aspects costs, quality and quantity are shown in Tab. 6.2, which represent the optimal levels of automation for each aspect in each Assembly Part of the Auto5000 assembly line in Wolfsburg as well as the values, which belong to these optimal levels.

As can be seen, in Assembly Part 1 the third level is the optimal level according to costs and quality. The results of quantity deliver the first level as the optimal level. In Assembly Part 2, level four is optimal for cost, quality and quantity. The fourth level is also the optimum regarding cost and quantity in Assembly Part 3. But with respect to quality, the first level is the optimal level. In the following chapter, the mentioned differences will be discussed to a total solution.

Auto5000 WOB Assembly Part 1			
Aspects	Level of automation		
	Optimal (value)		Actual
Costs	3	(14,72 €)	4
Quality	3	(0,01988 T.C./veh.)	
Quantity	1	(4,36 veh./h.)	

Auto5000 WOB Assembly Part 2			
Aspects	Level of automation		
	Optimal (value)		Actual
Costs	4	(11,63 €)	4
Quality	4	(0,02330 T.C./veh.)	
Quantity	4	(3,92 veh./h.)	

Auto5000 WOB Assembly Part 3			
Aspects	Level of automation		
	Optimal (value)		Actual
Costs	4	(7,29 €)	6
Quality	1	(0,00737 T.C./veh.)	
Quantity	4	(4,90 veh./h.)	

Tab. 6.2: Optimal levels of automation regarding costs in the three Assembly Part of Auto5000 manufacture in Wolfsburg
Source: Own presentation

6.2.2 Determination of the total optimal level of automation

In Assembly Part 1, the third level of automation is the optimal level with regard to costs and quality. This illustrates that the design of level 3 according to cost and quality points of views is optimal, but the actual level of automation in Assembly Part 1 is level of automation 4 in the Auto5000 GmbH. Regarding flexibility and productivity, level 1 is the optimal level for Assembly Part 1. Level 3 is just conditionally recommendable from the quantity's point of view because of its worse flexibility and productivity. So, there is a potential to automate the assembly in this part to a small extent.

As in Assembly Part 1, the optimal levels of automation regarding cost and quality correspond to each other in Assembly Part 2 as well. But, in this Assembly Part, level of automation 4 represents the actual level of automation. Between flexibility and productivity a compromise has to be found. At this, the decision is made for level 4, because only small changes in the number of workers and no changes in the assembly line have to be carried out at a still good productivity. As level of automation 4 is the optimal and also the actual level of automation, this Assembly Part is optimally designed.

As in chapter 6.1.2 the results of costs and quality differ from each other in Assembly Part 3. Exactly the same argumentation as is done above would lead to the correspondence of the optimal levels of automation with regard to costs and quality. Even when the main field in the Auto5000 manufacture is already based on the workers training, these training instructions have to be extended to guarantee a constant high-quality assembly. The above-mentioned improvements would cause a constant high-quality assembly. So, the optimal level of automation regarding quality corresponds to the optimal level of automation regarding costs. For quantity, level 4 is the optimum as well. This level is dimensioned in such a flexible way according to market fluctuations that no changes have to be carried out. Furthermore, level 4 provides a high technical availability.

6.3 Combination of the results of Golf A5 assembly in Uitenhage

6.3.1 Confrontation of the optimal levels of automation

The individual results of the three aspects cost, quality and quantity are shown in Tab. 6.3 on the following page, which represents the optimal levels of automation for each aspect in each Assembly Part of the Golf A5 assembly in Uitenhage. Furthermore, the values, which belong to the optimal levels, are shown in this table.

As can be seen, in Assembly Part 1 the fifth level is the optimal level according to costs and quantity. The results of quality deliver the third level as the optimal level. In Assembly Part 2, level four is optimal for quality and quantity. As in Assembly Part 1, the optimal level regarding costs is the fifth level. The seventh level is the optimum with regard to cost in Assembly Part 3, but with regard to quality and quantity the first level or rather the sixth level is the optimal level. In the following chapter, the mentioned differences will be discussed to a total solution.

Golf A5 SA Assembly Part 1			
Aspects	Level of automation		
	Optimal (value)		Actual
Costs	5	(6,48 €)	5
Quality	3	(0,01988 T.C./veh.)	
Quantity	5	(1,00 veh./h.)	

Golf A5 SA Assembly Part 2			
Aspects	Level of automation		
	Optimal (value)		Actual
Costs	5	(17,96 €)	5
Quality	4	(0,02330 T.C./veh.)	
Quantity	4	(1,28 veh./h.)	

Golf A5 SA Assembly Part 3			
Aspects	Level of automation		
	Optimal (value)		Actual
Costs	7	(8,22 €)	7
Quality	1	(0,00737 T.C./veh.)	
Quantity	6	(1,00 veh./h.)	

Tab. 6.3: Optimal levels of automation regarding costs in the three Assembly Part of Golf A5 manufacture in Uitenhage
Source: Own presentation

6.3.2 Determination of the total optimal level of automation

In Assembly Part 1, the results of costs and quality differ from each other like in 6.1.2, but, in this case exactly on the opposite way. The optimal level of automation regarding costs is more deautomated than the optimal level of automation regarding quality. The above-mentioned argumentation that manual assembly is as good as automatic assembly or even better is not valid for the manufacture in Uitenhage. The assembly in the station, which causes the differences[10] in a quality point of view again refer to roll-forming tailgate and doors. These stations are exactly carried out like in the manufacture of the Auto5000 GmbH, but they produce 0.101 trouble cases per vehicle more. This fact shows the deficits of the Golf A5 assembly in Uitenhage, which are already mentioned in 5.2.6. The leadership, training and qualification of workers are not adequate. The Auto5000 GmbH assembly line illustrates that a high-quality assembly by workers is possible in practice. The remedy of these deficits, as described in 6.2.2, would cause an improvement of quality. So, the optimal level of automation regarding quality corresponds to the optimal level of automation regarding costs. Assuming the actual situation in South Africa, level 5 can be seen as the optimum. This level is just a

[10] See Appendix H42

bit less flexible than level 4. The advantage of level 5 is the higher productivity towards level 4.

In Assembly Part 2, the optimal levels of automation with regard to costs and quality differ again from each other. In this Assembly Part, the differences are explainable by the above-mentioned reasons, too. All aspects that belong to the workers would have to be improved as described above. So, the optimal level of automation regarding quality corresponds to the optimal level of automation regarding costs. Level 4 is also the optimal level from the point of view of quantity. The actual and cost optimal situation is level 5. The advantages of level 5 are a better availability as well as a lower complexity.

As in chapters 6.1.2 and 6.2.2, the results of costs and quality differ from each other in Assembly Part 3. Exactly the same argumentation as is done above would lead to the correspondence of the optimal levels of automation with regard to costs and quality. But in the assembly of Uitenhage, especially, the already mentioned deficits in the bases of workers training and also the quality creating bases have to be remedied. If this will be realised, a high-quality performance in assembly should be possible like in the Auto5000 manufacture. So, the optimal level of automation regarding quality corresponds to the optimal level of automation regarding costs. Quantitatively, the levels 1 to 6 are all better than level 7. But level 7 is the actual level of automation in South Africa. Level 7 is just partially recommendable in terms of quantity, because this level shows worse values for flexibility and productivity compared to the other levels. Advantages of level 7 are the good availability and the small complexity of the equipment.

On the following page, the results of the confrontation are shown again in a more visible way. For each Assembly Part in each production site, three triangles show the actual situation (red coloured), the individual optima (green coloured) and finally the total optima (black coloured). The three axles represent the three aspects costs, quality and quantity. In each axle, the following ranges are significant:

- The range between the actual situation (red) and the total optimum (black):
  The intensity of the divergence between the actual and the optimal situation
- The range between the individual optimum (green) and the total optimum (black):
  The intensity of the efforts, which are necessary to correspond with the cost optimum or rather the total optimum

Golf A5 assembly in Wolfsburg

Assembly Part 1:

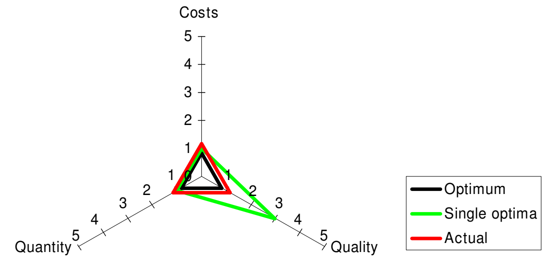

Fig. 6.13: Results of confrontation (Assembly Part 1)
Source: Own presentation

- The actual situation and the total optimum of costs, quality and quantity match in level 1.
- The optimum of quality differs to the total optimum in two levels.
- The individual optima of costs and quantity are identical to the total optimal level.

Assembly Part 2:

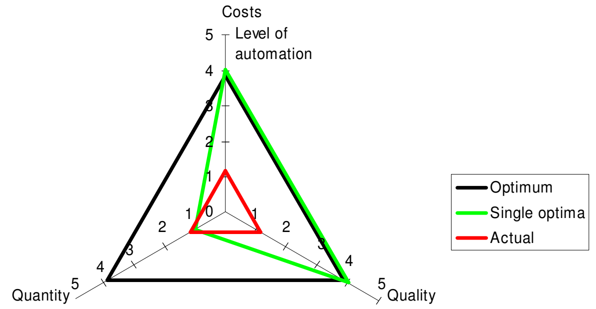

Fig. 6.14: Results of confrontation (Assembly Part 2)
Source: Own presentation

- The actual situation of costs and quantity is level 1.
- The total optimum for all three criteria is level 4.
- To change from the actual situation, level 1, to the total optimal level, deautomation has to be carried out.
- The quantitative optimum differs in 3 levels to the total optimum, which is the lower automated level.

Assembly Part 3:

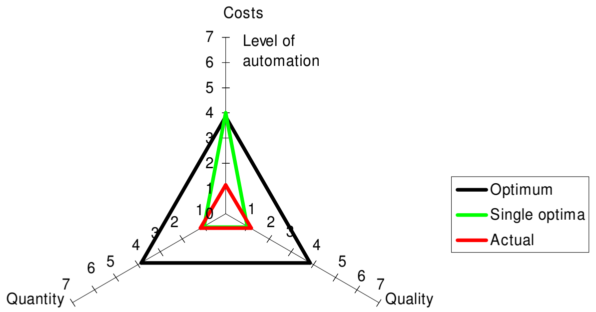

Fig. 6.15: Results of confrontation (Assembly Part 3)
Source: Own presentation

- Level 1 shows the actual situation. The total optimum is level 4.
- To reach the total optimum a deautomation has to take place.
- The individual optimum of quality and quantity is each level 1.
- The difference between them and the total optimum is three levels.

Auto5000 assembly in Wolfsburg

Assembly Part 1:

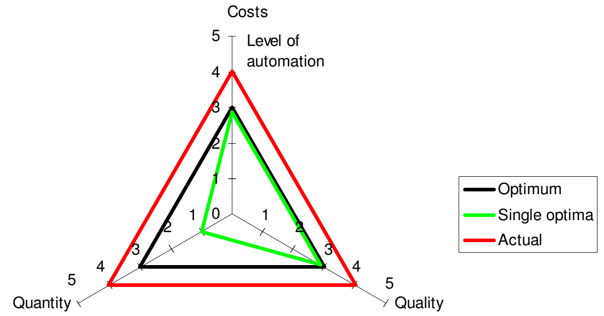

Fig. 6.13: Results of confrontation (Assembly Part 1)
Source: Own presentation

- The actual situation is level 4. The total optimum is in level 3.
- The quantitative optimum has a difference of two levels to the total optimum.
- From all points of view, the Assembly Part 1 has to be automated.

Assembly Part 2:

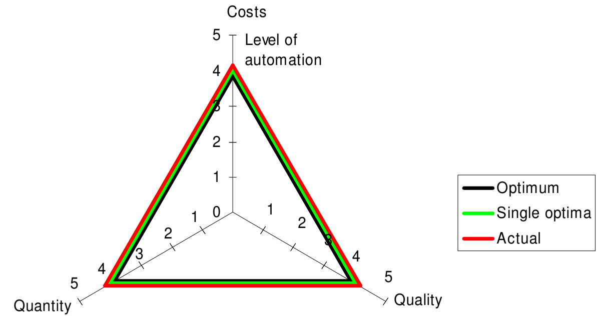

Fig. 6.14: Results of confrontation (Assembly Part 2)
Source: Own presentation

- This part is optimally designed with level 4. The actual situation, the total optimum and the individual optima show level 4.

Assembly Part 3:

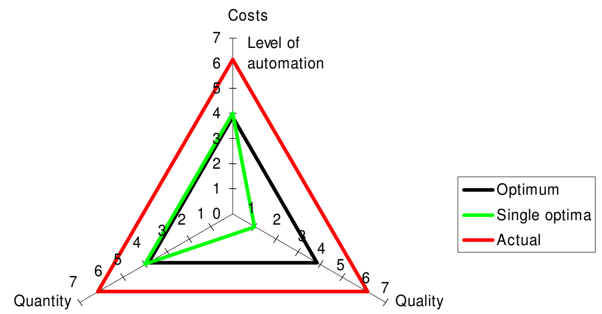

Fig. 6.15: Results of confrontation (Assembly Part 3)
Source: Own presentation

- Related to costs, quality and quantity the actual situation is level 6.
- The total optimum is level 4.
- This Assembly Part has to be automated to change from level 6 to level 4.
- The individual optimum of quality has a difference of two levels to the optimal level.

Golf A5 assembly in Uitenhage

Assembly Part 1:

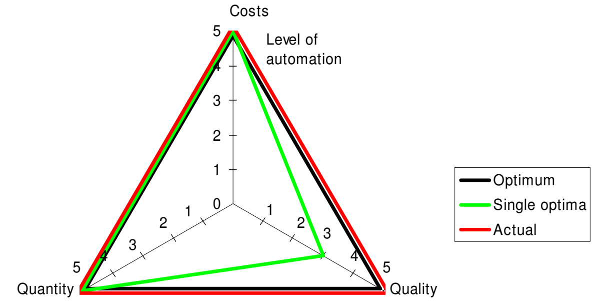

Fig. 6.13: Results of confrontation (Assembly Part 1)
Source: Own presentation

- The actual situation and the total optimum are optimally designed with level 5.
- The qualitative optimum has a difference of 2 levels against the total optimum.

Assembly Part 2:

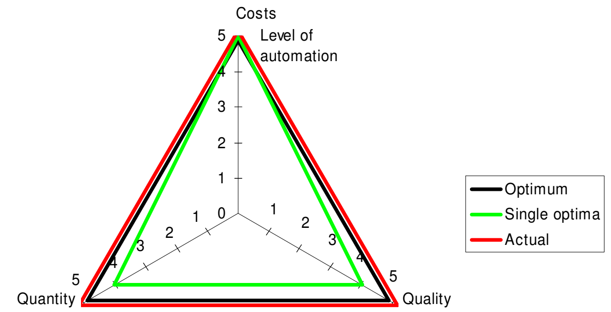

Fig. 6.14: Results of confrontation (Assembly Part 2)
Source: Own presentation

- The total optimum as well as the actual situation corresponds to level 5.
- The qualitative and quantitative optima are with level 4 only one step of automation in direction of automation away from the total optimum.

Assembly Part 3:

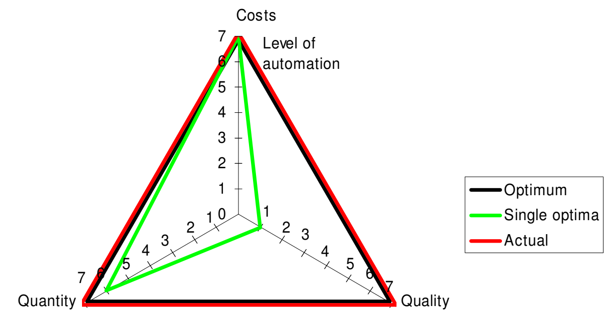

Fig. 6.15: Results of confrontation (Assembly Part 3)
Source: Own presentation

- Costs, quality and quantity match in the actual situation and the total optimum with level 7.
- The quantitative optimum shows a difference of one level and the qualitative optimum of six levels related to the optimal level.

7. Conclusion

Today's leading vehicle manufacturers have to cope with increasing competition. Growing market demands, short reaction times to develop new products and high-price pressure are the basic conditions the companies are confronted with. They stand for complete satisfaction of customers' demands and furthermore for absolute quality awareness, strategic dynamics and flexibility. Volkswagen AG represents one of these manufacturers that have to fulfil these abilities as well as possible to stay competitive. Especially in Europe, large over-capacities cause too many produced vehicles that have to sell at a low profit too often. The result is an increasing pressure of competition that Volkswagen AG has to fulfil. Because of this, it is of great significance to produce and market high-quality products at reasonable price. This is why cost optimal manufacturing and observing the delivery deadline are the most important factors to fulfil the mentioned requirements on the market and to make a high profit at the same time.

In this master thesis, the assembly lines of three different production sites of Volkswagen AG were analysed regarding costs, quality and quantity. To enable the connection of all parts of the project as far as possible, the same basis had to be provided before starting the analysis. This basis was reached with the creation of comparable levels of automation, which could be shown clearly in matrixes based on morphological boxes that show the possibilities of how to fulfil the certain operations in each considered station. All stations that are put together in the highly automated areas in the Golf A5 assembly line in Wolfsburg, which are called Mechanisations, were chosen and examined in all of the three production sites of the Golf A5 in Wolfsburg, the Touran in the Auto5000 in Wolfsburg and the Golf A5 in Uitenhage, South Africa. The levels of automation that require the lowest costs per unit represent the optimal levels of automation regarding costs. By defining these levels as the basis, the modifications, which would have to be done in the optimal levels regarding quality and quantity, have to be argued to correspond to the cost optimal levels.

As a result, a potential for optimising exists. Above all, the production sites in Wolfsburg have a high potential. The results of the Golf A5 assembly line in Wolfsburg illustrate that the examined Assembly Parts 2 and 3 have to be deautomated. Assembly Part 1 is designed optimally, whereas a quality improvement by modifications as mentioned in Ch. 6.1.2 is to be aspired in this part. The actual level of automation in

Assembly Part 2 has to be deautomated to reach the total optimal level. But in this part necessary quantity adaptations, which are also dealt with in Ch. 6.1.2, have to be considered. In Assembly Part 3 the actual level of automation has to be deautomated to reach the optimal level as well. There, the quality as well as the quantity modifications should be kept in mind.

The examined Assembly Parts in the production site of the Auto5000 GmbH in Wolfsburg have to be automated to a small extent in general according to the determined results. This conclusion is valid for Assembly Part 1 and 3, which have to be automated from the actual levels of automation to reach the optimal levels. The necessary quantity variations have to be considered in both parts. Additionally in Assembly Part 3 the quality improvements (see Ch. 6.2.2) have to be aimed at. The actual level of automation in Assembly Part 2 represents the total optimal level of automation in all aspects. Hence, this part is already optimally designed.

The actual levels of automation in the Golf A5 assembly line in Uitenhage are optimally designed according to the determined results. But, especially from a quality point of view, the deficits (see Ch. 6.2.3) have to be remedied. The manufacture of the Auto5000 GmbH illustrates that a manual assembly with high quality is possible in practice. So, the manufacture in Uitenhage has to be adapted to this to produce a better quality in the actual and optimal determined level of automation.

Additionally, a varying number of units in the cost analyses would lead to different optimal levels of automation depending on the number of units. Generally, the costs run exponentially with the increasing level of automation. Simultaneously, costs decrease with a growing number of units, because the fixed costs are divided between more units. The more the system is used to capacity the lower the total costs per unit develop. It is possible that the investments for automation are so high that even for the maximum number of units, the total costs for a high level of automation are higher than the costs for manual assembly. In practice it is shown that for the most part, costs per unit are minimal in semi-automated systems. Mainly, high automation is only profitable for large numbers of produced units.

Varying certain parameters of the calculation would show effects on costs per unit. The more the system is automated, the greater the influence on costs per unit will be. Introducing a 5-day week without pay compensation in the assembly line of the Golf A5 in Wolfsburg would lead to great cost savings as well.

Finally, a consideration of the total assembly line would show that Hall 54, in where the assembly of the Golf A5 takes place, is extremely inflexible. Possible economical advantages are wrecked by chain losing, standstill losing, high technical support and high costs for rebuilding in the case of new variants. These theses can be confirmed by the Fraunhofer Institut, which carried out a study about the assembly line of the Golf A5 as well.[1] Highly automated systems cause decreasing flexibility of numbers of units, variants and adjustments. Costs for interruptions can be compensated by increased numbers of buffers and over-dimensioned facilities. But, both of these functions increase costs. Higher automation would only lead to satisfaction and cost-optimal manufacturing if systems were designed modularly, which can be converted simply.

The results of the analysis have shown that a potential for optimisation exists, especially in the assembly line of the Golf A5 in Wolfsburg. It exists in the design of single stations as well as in the design of the total system. With the investigation methods that have been carried out in this master thesis, a new potential for optimal manufacturing at lowest costs and best quality can be exploited.

A similar investigation was carried out for the bodyshops of the three production sites. Due to the component size in the bodyshop, it must be equipped with a high degree of automation. Nevertheless, potentials for deautomating could be carried out. This is meant in particular for a highly and in a complex way automated body manufacturing. In this case, the potential does not focus on a lowering of the degree of automation. It concentrates in different automation concepts. Here, complexity and flexibility are two important aspects. Usually, a flexible manufacturing plant can be designed only with a high degree of complexity. The problem of high complexity is a strong vulnerability to failures of the production system. Therefore, the optimum of complexity and flexibility must be found with regard to the economy of the production system. Due to the investigation and also confirmed by the studies of the Harbour Report, the degree of automation in the bodyshop should have level 2 in high-wage countries and level 3 or rather level 4 in low-wage countries.

In the following chapter, an overview will give advice for the optimal assembling in the production sites of the Golf A5 in Wolfsburg, the Auto5000 GmbH in Wolfsburg as well as the Golf A5 in Uitenhage.

[1] See Lay 2001, p. 399

8. Recommendations

In the future, vehicles will no longer be a mass product. Moreover, the number of variants will even increase more, because in each vehicle class several variants and models (cabriolet, SUV, etc.) will be demanded on the market. Flexibility becomes more and more important because of the modifications in the market. These are especially:

- **Product life cycles are getting shorter**: The results are frequent product rotations, less time to develop new products, less time for production optimising.
- **Customers want a higher variety of types and variants**: The consequence is a higher expenditure of planning and control as well as a higher expenditure in development.
- **There is an increase in international competition**: The consequence is a growing price pressure and therefore, a growing pressure on production costs and a faster conversion of technical improvement.
- **The customer's behaviour changes**: The consequences are demands with respect to individual solutions and a higher quality consciousness.

So, assembling systems, which flexibly adapt to the market demands become necessary. It is essential to design the assembly according to the claimed vehicles and not vice versa design the vehicles according to the existing design of the assembly.

The concepts have to have small fixed costs only to keep costs per unit almost constant during fluctuations. Companies are forced to produce many variants to be able to fulfil the special demands of customers in different markets with amended products. Long turn-around times and high stocks are not acceptable in the future, which requires more a flexible and economical assembly. Therefore, manual assembly becomes more important. It is practical to integrate as much flexibility into the production systems as possible.

The conclusion of these developments will be to create small, flexible and manageable production sites, which have small depreciations. Furthermore, the characteristics of these manufactures are small and flexible assembly lines, which are exactly adapted to the local peculiarities, high manpower requirements including flexible collective agreement, a high level of know-how as well as a high efficiency.

The following page will be the end of the analyses. On this page, the general procedure of introducing a new product and recommendations for designing an assembly line in the determined production sites will be presented.

Fig. 8.1 shows the general procedure for introducing a new product. The first part describes the development of the new vehicle. After designing and planning the vehicle has to be constructed. Not until Part I is finished, a suitable location for manufacturing the new product has to be chosen. Amongst other parameters (for instance settled suppliers in the potential location or expenditure for transporting certain components of the vehicle), primarily aspects of costs, quality and quantity have to be considered before choosing the location. Especially, personnel cost rates and costs for providing energy have great influences on the total costs of manufactured vehicles per unit. For securing the high product quality of Volkswagen, a high education and motivation of the employees is absolutely necessary. From a quantitative point of view, the sales market with possible market fluctuations have to be analysed.

If all of these aspects are considered, the location for a new production site can be chosen and after that, the production system with the most economical level of automation can be determined with consideration of the mentioned aspects. But, in addition to the optimal level, it is very important to design the production plant around the claims of the product and not in reverse (see thunders). Furthermore, the product construction should be simple.

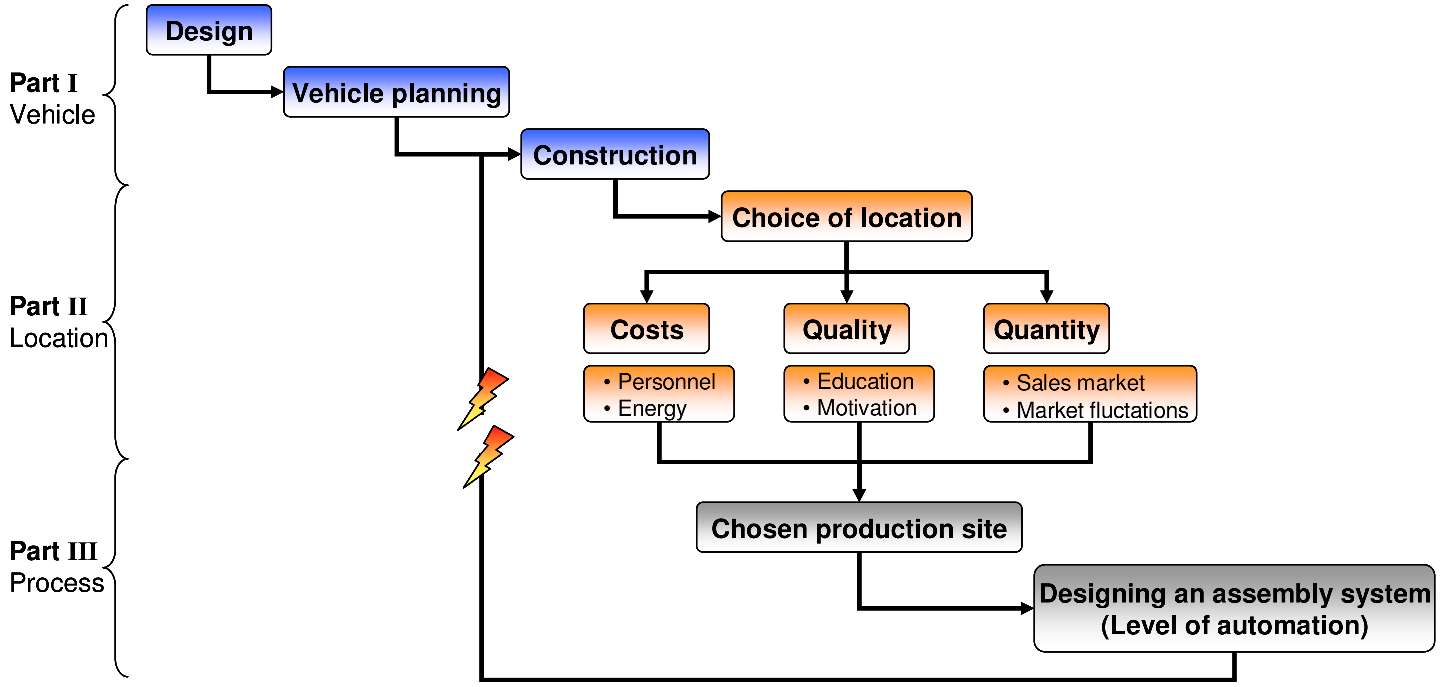

Fig. 8.1: General procedure for introducing a new product
Source: Own presentation

Recommendations

Golf A5 assembly in Wolfsburg

- **The following stations have to be deautomated:**
  Assembly Part 1: none
  Assembly Part 2: Stamping VINs, fitting gear shift, closing bonnet, fitting all glasses (all like in Auto5000 GmbH)
  Assembly 3: Opening bonnet, putting in and fitting CW-trim panel, putting in and fitting battery, fitting cross member and rear bumper (all like in Auto5000 GmbH)
- **Solution for ordering the stations:** Redesigning the line by reordering stations in the areas where parts are assembled manually (Assembly Part 2) or rather designing a new system (Assembly Part 3)
- **Advantages of the new system:**
  - Reduction of costs
  - Less or rather smaller buffers are necessary
  - Differences between high and low automation become smaller which makes the system more stable
  - More flexible towards tolerance problems
  - Workers are more applicable than machines
- **Quality demands:**
  - Improving the automatic roll-forming process
  - Educating the workers for manual assembling, especially in the stations fitting cross member and rear bumper
- **Quantity demands:**
  - Scalable hybrid systems lead to adjustable production systems that are cost-optimal to fluctuating demands.
  - Shortening the period of depreciation leads to increasing flexibility, which is necessary for decreasing product life cycles and growing numbers of face-liftings in the future.
- A change of the pay scale system from 4 days to 5 days per week causes reduced costs per unit and standstill times as well as a higher capacity utilisation rate of the system.

Auto5000 assembly in Wolfsburg

- **The following stations have to be automated:**
  Assembly Part 1: fitting cockpit (like in Golf A5 Wolfsburg)
  Assembly Part 2: none
  Assembly Part 3: fitting frontend, premounting and fitting wheels, placing spare wheel in boot
- **Solution for ordering the stations:** Reorganising the line by placing the stations that have to be automated in front of or rather behind the existing lines, where parts are assembled manually
- **Advantages of the optimised system:**
  - Reducing of costs
- **Demands on quality:** All changes of the stations would lead to quality improvement
- **Demands on quantity:** Even more automation leads to a better productivity but would override the actual high effectiveness because of decreasing the availability

Golf A5 assembly in Uitenhage

- **The following stations have to be automated:**
  Assembly Part 1: none
  Assembly Part 2: none
  Assembly Part 3: none
- **Solution for ordering the stations:** The line is already optimal designed
- **Demands on quality:**
  - Improving the manual rollforming process, the VIN stamping as well as the manual stations fitting rear and front bumper, fitting frontend and placing spear wheel in boot
  - Improving the qualification, organisation and motivation of workers (like in both of the other determined production sites, especially like in Auto5000 GmbH)
  - Improving the leadership (like in both of the other determined production sites, especially like in Auto5000 GmbH)
  - Complete installation of Quality Control Circles (QCC) (like in both of the other determined production sites)
- **Demands on quantity:** none

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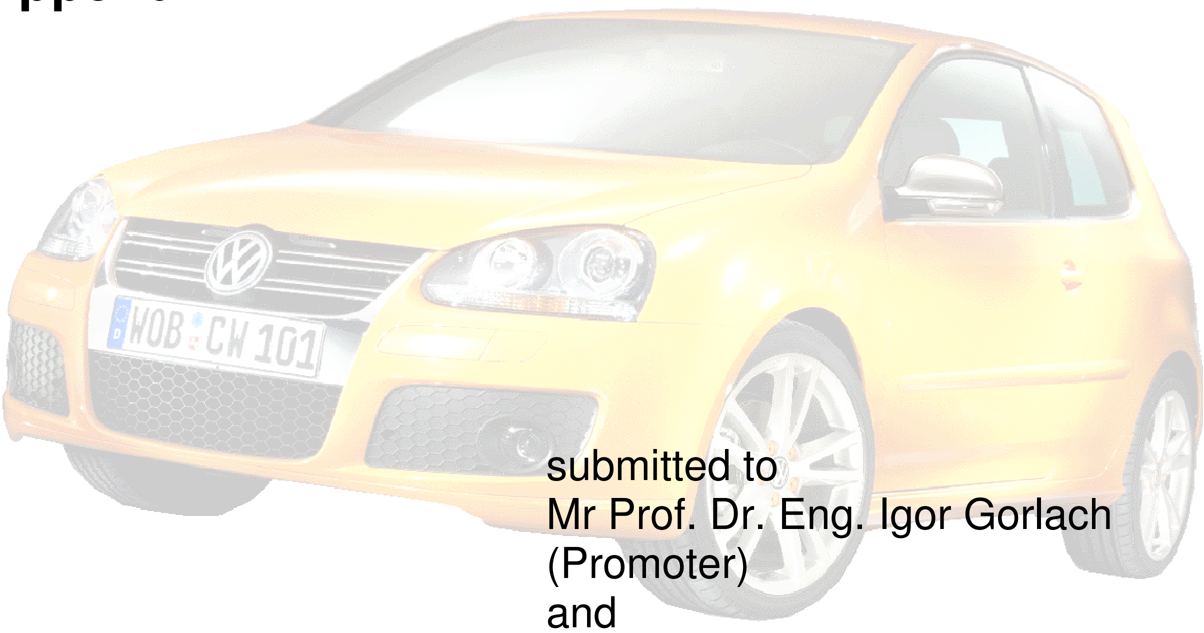
Comparative Study of Automation Strategies at VW Germany and South Africa

Appendix



submitted to
Mr Prof. Dr. Eng. Igor Gorlach
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and
Mr Prof. Dr.-Ing. Holdack-Janssen
(Supervisor)

written by
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Account number 20691224

Wolfsburg, August 2006

Matrixes with corrected results

AP1 theo. cor.	A	B	C	D	E	F	G	H	I	J	K	L	M
Manufacturing stations / Level of automation	Rollforming tailgate	Fitting cockpit location brackets	Rollforming doors	Cleaning window flange, Closing tailgate	Priming window flange, Opening bonnet	Applying cockpit glue	Cockpit fitting 1	Removing cable box, Remaining screw connections	Remaining screw connections	Cockpit fitting 2	Removing cable box, Remaining screw connections	Remaining screw connections	Total
Level of automation (Golf A5 WOB)	FISeQS (T.C./veh.) 0,00503	FISeQS (T.C./veh.) 0,00003	FISeQS (T.C./veh.) 0,00358	FISeQS (T.C./veh.) 0,00002	FISeQS (T.C./veh.) 0,00051	FISeQS (T.C./veh.) 0,00025					FISeQS (T.C./veh.) 0,01543		FISeQS (T.C./veh.) 0,02484
Level of automation (Auto5000 WOB)	myprocess (T.C./veh.) 0,00188	myprocess (T.C./veh.) n. a.	myprocess (T.C./veh.) 0,00229	myprocess (T.C./veh.) n. a./n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n.d.	myprocess (T.C./veh.)				myprocess (T.C./veh.) 0,03950		myprocess (T.C./veh.) 0,04367
Opt. level of automation (theoretical corrected)	myprocess (T.C./veh.) 0,00188	FISeQS (T.C./veh.) 0,00003	myprocess (T.C./veh.) 0,00229	FISeQS (T.C./veh.) 0,00002	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n.d.					FISeQS (T.C./veh.) 0,01543		FISeQS (T.C./veh.) 0,01965

Assembly Part 1, level of automation with corrected results

AP2 theo. cor.	A	B	C	D	E	F	G	H	I
Manufacturing stations / Level of automation	Stamping vehicle identification number (VIN) (3 times)	Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	Fitting gear shift	Closing bonnet	Lifting down	Fitting windscreen 1, Fitting rear glass 1	Fitting windscreen 2, Fitting rear glass 2	Fitting side glasses	Total
Level of automation (Golf A5 WOB)	FISeQS (T.C./veh.) 0,00416	FISeQS (T.C./veh.) 0,01030	FISeQS (T.C./veh.) 0,00016	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,01917		FISeQS (T.C./veh.) 0,00390	FISeQS (T.C./veh.) **0,03769**
Level of automation (Auto5000 WOB)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00645	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,01392		myprocess (T.C./veh.) 0,00293	myprocess (T.C./veh.) **0,02330**
Opt. level of automation (theoretical corrected)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00645	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,01392		myprocess (T.C./veh.) 0,00293	FISeQS (T.C./veh.) **0,02330**

Assembly Part 2, level of automation with corrected results

AP3 theo. cor.	A	B	C	D	E	F	G	H	I	J	K
Manufacturing stations / Level of automation	Opening bonnet	Putting in/Fitting the CW trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels	Total
Level of automation (Golf A5 WOB)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00109	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.) 0,00061	FISeQS (T.C./veh.) **0,00737**
Level of automation (Auto5000 WOB)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00128	myprocess (T.C./veh.) 0,00412		myprocess (T.C./veh.) 0,00142	myprocess (T.C./veh.) 0,01642	myprocess (T.C./veh.) 0,00438		myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00154	myprocess (T.C./veh.) **0,02916**
Opt. level of automation (theoretical corrected)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00109	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00061	FISeQS (T.C./veh.) **0,00711**

Assembly Part 3, level of automation with corrected results

AP1 theo. cor.	A	B	C	D	E	F	G	H	I	J	K	L
Manufacturing stations / Level of automation	Rollforming tailgate	Fitting cockpit location brackets	Rollforming doors	Cleaning window flange, Closing tailgate	Priming window flange, Opening bonnet	Applying cockpit glue	Cockpit fitting 1	Removing cable box, Remaining screw connections	Remaining screw connections	Cockpit fitting 2	Removing cable box, Remaining screw connections	Remaining screw connections
Level of automation (Golf A5 WOB)	automatic (1 robot)	automatic (2 facilities)	automatic (4 robots)	automatic (3 robots)	automatic (3 robots)	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)
Level of automation (Auto5000 WOB)	manual (handrollfor-ming device)		manual (handrollfor-ming device)	manual	manual	automatic (1 robot)	manual (manipulator with sensors and electrical screwdriver)			manual (manipulator and electrical screwdriver)		
Opt. level of automation (theoretical corrected)	manual (handrollfor-ming device)	automatic (2 facilities)	manual (handrollfor-ming device)	automatic (3 robots)	manual	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)

Assembly Part 1, level of automation with corrected results

AP2 theo. cor.	Manufacturing stations / Level of automation	Level of automation (Golf A5 WOB)	Level of automation (Auto5000 WOB)	Opt. level of automation (theoretical corrected)
A	Stamping Vehicle Identification Number (VIN) (3 times)	automatic (2 robots and 1 facility)	manual (3 manipula-tors)	manual (3 manipula-tors)
B	Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	automatic (18 facilities, 1 robot and 1 lifter)	automatic (18 facilities, 1 robot and 1 lifter)	automatic (18 facilities, 1 robot and 1 lifter)
C	Fitting gear shift	automatic (1 robot)	manual (accu screw-driver)	manual (accu screw-driver)
D	Closing bonnet	automatic (1 robot)	manual	automatic (1 robot) / manual
E	Lifting down	automatic (3 facilities and 1 lifter)	automatic (3 facilities and 1 lifter)	automatic (3 facilities and 1 lifter)
F	Fitting windscreen 1, Fitting rear glass 1	automatic (2 robots)	manual (2 robots)	manual (2 robots)
G	Fitting windscreen 2, Fitting rear glass 2	automatic (2 robots)		
H	Fitting side glasses	automatic (4 robots)	manual (1 robot)	manual (1 robot)

Assembly Part 2, level of automation with corrected results

AP3 theo. cor.	A	B	C	D	E	F	G	H	I	J
Manufacturing stations / Level of automation	Opening bonnet	Putting in/Fitting the CW-trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels
Level of automation (Golf A5 WOB)	automatic (1 facility)	automatic (2 facilities)	automatic (1 robot and 0,5 mani-pulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)
Level of automation (Auto5000 WOB)	manual	manual (accu screw-driver)	manual (accu screwdriver)		manual (electrical screwdriver)	manual (accu screw-driver)	manual (manipulator with sensory)	manual (accu screw-driver)	manual (manipulator)	manual (2 supporters, accu screw-driver and 2 manipulator)
Opt. level of automation (theoretical corrected)	automatic (1 facility) manual	automatic (2 facilities)	automatic (1 robot and 0,5 mani-pulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		manual (manipulator)	automatic (4 facilities)

Assembly Part 3, level of automation with corrected results

Konzern Audit

Golf/Jetta Konzern Training March 2006

Av. QC is 2.2 Konzern

Units QC: 2.3, 2.1, 2.1, 1.9, 1.8, 3.3

By Resp. Area	
Press Shop	71,4
Body Shop	271,4
Paint Shop	82,9
Assembly	244,3
Supply	131,4

Current QC is 1.6 South Africa

By Resp. Area	
Press Shop	75
Body Shop	191,7
Paint Shop	60
Assembly	128,3
Supply	105

=> 244,3/128,3= 1,90

Problems	Code	Resp Person	Golf 3 months 43 cars	non report 3 months 27 cars	Jetta 3 months 9 cars	non report 3 months 31 cars
Fitment						
Rear Door Left fitment	B		6	7	1	19
Decklid Fitment	B1		10	12	4	15
Bonnet Fitment	B1		2	6	2	7
Rear Bumper Fitment	B		0	2	0	5
L Rear door Closing force to high	B		0	0	0	1
Rear Door R Inner retain screw top paint	B		0	1	0	1
R Rear Door Closing force to high	B1		0	0	0	0
Dents						
Decklid Dent	B1		1	0	2	8
Bonnet dent	B		1	1	1	5
Sill Dent Bottom	B1		0	0	0	0
L Front Fender Dent	B		1	0	0	0
R Front Door Dent inner	B		0	0	0	0
Assembly						
R Front Door Seal Loose	B		2	1	3	8
Headlamp Setting	B		0	3	0	1
CD Player Loose	B		1	1	1	1
Sunroof Fitment	B		0	0	0	0
L Rear door Scratch on hinge	B		1	1	0	0
Boot Wire loose	B		1	0	0	0
R Front outer cover Dent	B		0	0	0	2
Sunroof Dirty	B		0	0	0	0
Centre Consol loose and Damaged	B1		0	0	0	0
Paint						
Decklid Polish Mark	B		2	0	1	0
Decklid Hinges Scratches	B1		0	0	0	0
Decklid Fitment	B1		0	0	0	0
Colour deviation on Bumber and lower strip	B		1	0	0	0
Rear seat locks function	B1		0	0	0	0

Results of Konzern Audit in March 2006, Source: Konzern Qualitätssicherung, VW Wolfsburg

Appendix I

Assessment of the results:

Konzern Audit report, corrected and final results

Matrixes with theoretical created level of automation with the fewest defects

AP1 theo – Manufacturing stations / Level of automation	A Rollforming tailgate	B Fitting cockpit location brackets	C Rollforming doors	D Cleaning window flange, Closing tailgate	E Priming window flange, Opening bonnet	F Applying cockpit glue	G Cockpit fitting 1	H Removing cable box, Remaining screw connections	I Remaining screw connections	J Cockpit fitting 2	K Removing cable box, Remaining screw connections	L Remaining screw connections	M Total
Level of automation (Golf A5 WOB)	FISeQS (T.C./veh.) 0,00503	FISeQS (T.C./veh.) 0,00003	FISeQS (T.C./veh.) 0,00358	FISeQS (T.C./veh.) 0,00002	FISeQS (T.C./veh.) 0,00051	FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.)				FISeQS (T.C./veh.) 0,01543		FISeQS (T.C./veh.) 0,02484
Level of automation (Auto5000 WOB)	myprocess (T.C./veh.) 0,00188	myprocess (T.C./veh.) n. a.	myprocess (T.C./veh.) 0,00229	myprocess (T.C./veh.) n. a./n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n.d.		myprocess (T.C./veh.)			myprocess (T.C./veh.) 0,03950		myprocess (T.C./veh.) 0,04367
Level of automation (Golf A5 SA)	FISeQS (T.C./veh.) 0,05698	FISeQS (T.C./veh.) 0,00081	FISeQS (T.C./veh.) 0,04819	FISeQS (T.C./veh.) n. a./n. d.	FISeQS (T.C./veh.) n. d.			FISeQS (T.C./veh.) 0,00677					FISeQS (T.C./veh.) 0,11275
Opt. level of automation (theoretical)	myprocess (T.C./veh.) 0,00188	FISeQS (T.C./veh.) 0,00003	myprocess (T.C./veh.) 0,00229	FISeQS (T.C./veh.) 0,00002	myprocess (T.C./veh.) n. d.			FISeQS (T.C./veh.) 0,00677					FISeQS (T.C./veh.) 0,01099

Assembly Part 1, level of automation with theoretically fewest defects

AP2 theo Manufactu-ring stations / Level of automation	A Stamping vehicle identification number (VIN) (3 times)	B Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	C Fitting gear shift	D Closing bonnet	E Lifting down	F Fitting windscreen 1, Fitting rear glass 1	G Fitting windscreen 2, Fitting rear glass 2	H Fitting side glasses	I Total
Level of automation (Golf A5 WOB)	FISeQS (T.C./veh.) 0,00416	FISeQS (T.C./veh.) 0,01030	FISeQS (T.C./veh.) 0,00016	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,01917		FISeQS (T.C./veh.) 0,00390	FISeQS (T.C./veh.) **0,03769**
Level of automation (Auto5000 WOB)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00645	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,01392		myprocess (T.C./veh.) 0,00293	myprocess (T.C./veh.) **0,02330**
Level of automation (Golf A5 SA)	FISeQS (T.C./veh.) 0,00920	FISeQS (T.C./veh.) 0,01245	FISeQS (T.C./veh.) 0,00027	FISeQS (T.C./veh.) n. d.		FISeQS (T.C./veh.) 0,00920		myprocess (T.C./veh.) n. a.	FISeQS (T.C./veh.) **0,03113**
Opt. level of automation (theoretical)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00645	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00920		myprocess (T.C./veh.) 0,00293	FISeQS (T.C./veh.) **0,01858**

Assembly Part 2, level of automation with theoretically fewest defects

AP3 theo Manufactu-ring stations / Level of automation	A	B	C	D	E	F	G	H	I	J	K
	Opening bonnet	Putting in/Fitting the CW trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels	Total
Level of automation (Golf A5 WOB)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00109	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.) 0,00061	FISeQS (T.C./veh.) **0,00737**
Level of automation (Auto5000 WOB)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00128	myprocess (T.C./veh.) 0,00412		myprocess (T.C./veh.) 0,00142	myprocess (T.C./veh.) 0,01642	myprocess (T.C./veh.) 0,00438		myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00154	myprocess (T.C./veh.) **0,02916**
Level of automation (Golf A5 SA)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00027	FISeQS (T.C./veh.) 0,01299		FISeQS (T.C./veh.) 0,00014	FISeQS (T.C./veh.) 0,09285	FISeQS (T.C./veh.) 1,41933		FISeQS (T.C./veh.) 0,01381	FISeQS (T.C./veh.) 0,00352	FISeQS (T.C./veh.) **1,54291**
Opt. level of automation (theoretical)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00027	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00061	FISeQS (T.C./veh.) **0,00629**

Assembly Part 3, level of automation with theoretically fewest defects

AP1 theo	A	B	C	D	E	F	G	H	I	J	K	L
Manufacturing stations / Level of automation	Rollforming tailgate	Fitting cockpit location brackets	Rollforming doors	Cleaning window flange, Closing tailgate	Priming window flange, Opening bonnet	Applying cockpit glue	Cockpit fitting 1	Removing cable box, Remaining screw connections	Remaining screw connections	Cockpit fitting 2	Removing cable box, Remaining screw connections	Remaining screw connections
Level of automation (Golf A5 WOB)	automatic (1 robot)	automatic (2 facilities)	automatic (4 robots)	automatic (3 robots)	automatic (3 robots)	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)
Level of automation (Auto5000 WOB)	manual (handrollfor-ming device)		manual (handrollfor-ming device)	manual	manual	automatic (1 robot)	manual (manipulator with sensors and electrical screwdriver)			manual (manipulator and electrical screwdriver)		
Level of automation (Golf A5 SA)	manual (handrollfor-ming device)	manual (electrical screwdriver and jigs)	manual (handrollfor-ming device)	manual	manual	manual (manipulator without sensors , electrical screwdriver and 1 system)						
Opt. level of automation (theoretical)	manual (handrollfor-ming device)	automatic (2 facilities)	manual (handrollfor-ming device)	automatic (3 robots)	manual	manual (manipulator without sensors , electrical screwdriver and 1 system)						

Assembly Part 1, level of automation with theoretically fewest defects and how it is to be put into practise

AP2 theo	Manufacturing stations / Level of automation	Level of automation (Golf A5 WOB)	Level of automation (Auto5000 WOB)	Level of automation (Golf A5 SA)	Opt. level of automation (theoretical)
A	Stamping Vehicle Identification Number (VIN) (3 times)	automatic (2 robots and 1 facility)	manual (3 manipula-tors)	manual (3 manipula-tors)	manual (3 manipula-tors)
B	Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	automatic (18 facilities, 1 robot and 1 lifter)	automatic (18 facilities, 1 robot and 1 lifter)	manual (3 facilities and 1 lifter)	automatic (18 facilities, 1 robot and 1 lifter)
C	Fitting gear shift	automatic (1 robot)	manual (accu screw-driver)	manual (accu screw-driver)	manual (accu screw-driver)
D	Closing bonnet	automatic (1 robot)	manual	manual	automatic (1 robot) / manual
E	Lifting down	automatic (3 facilities and 1 lifter)	automatic (3 facilities and 1 lifter)		automatic (3 facilities and 1 lifter)
F	Fitting windscreen 1, Fitting rear glass 1	automatic (2 robots)	manual (2 robots)	manual (2 robots)	manual (2 robots)
G	Fitting windscreen 2, Fitting rear glass 2	automatic (2 robots)			
H	Fitting side glasses	automatic (4 robots)	manual (1 robot)		manual (1 robot)

Assembly Part 2, level of automation with theoretically fewest defects and how it is to be put into practise

AP3 theo	A	B	C	D	E	F	G	H	I	J
Manufacturing stations / Level of automation	Opening bonnet	Putting in/Fitting the CW-trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels
Level of automation (Golf A5 WOB)	automatic (1 facility)	automatic (2 facilities)	automatic (1 robot and 0,5 mani-pulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)
Level of automation (Auto5000 WOB)	manual	manual (accu screw-driver)	manual (accu screwdriver)		manual (electrical screwdriver)	manual (accu screw-driver)	manual (manipulator with sensors)	manual (accu screw-driver)	manual (manipulator)	manual (2 supporters, accu screw-driver and 2 manipulator)
Level of automation (Golf A5 SA)	manual	manual (accu screw-driver)	manual (accu screwdriver)		manual (electrical screwdriver)	manual (accu screw-driver)	manual (manipulator without sensors)	manual (accu screw-driver)	manual	manual (electrical screwdriver)
Opt. level of automation (theoretical)	automatic (1 facility) / manual	manual (accu screw-driver)	automatic (1 robot and 0,5 mani-pulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		manual (manipulator)	automatic (4 facilities)

Assembly Part 3, level of automation with theoretically fewest defects and how it is to be put into practise

Matrixes with fictitious created level of automation

AP1	A	B	C	D	E	F	G	H	I	J	K	L
Manufacturing stations / Level of automation	Rollforming tailgate	Fitting cockpit location brackets	Rollforming doors	Cleaning window flange, Closing tailgate	Priming window flange, Opening bonnet	Applying cockpit glue	Cockpit fitting 1	Removing cable box, Remaining screw connections	Remaining screw connections	Cockpit fitting 2	Removing cable box, Remaining screw connections	Remaining screw connections
Level of automation 1 (Golf A5 WOB)	automatic (1 robot)	automatic (2 facilities)	automatic (4 robots)	automatic (3 robots)	automatic (3 robots)	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)
Level of automation 2	manual (handrollforming device)	automatic (2 facilities)	manual (handrollforming device)	automatic (3 robots)	automatic (3 robots)	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)
Level of automation 3	manual (handrollforming device)	automatic (2 facilities)	manual (handrollforming device)	manual	manual	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)
Level of automation 4 (Auto5000 WOB)	manual (handrollforming device)	manual (electrical screwdriver and jigs)	manual (handrollforming device)	manual	manual	automatic (1 robot)	manual (manipulator with sensors and electrical screwdriver)	manual (manipulator with sensors and electrical screwdriver)	manual (manipulator with sensors and electrical screwdriver)	manual (manipulator and electrical screwdriver)	manual (manipulator and electrical screwdriver)	manual (manipulator and electrical screwdriver)
Level of automation 5 (Golf A5 SA)	manual (handrollforming device)	manual (electrical screwdriver and jigs)	manual (handrollforming device)	manual	manual	manual (manipulator without sensors, electrical screwdriver and 1 system)	manual (manipulator without sensors, electrical screwdriver and 1 system)	manual (manipulator without sensors, electrical screwdriver and 1 system)	manual (manipulator without sensors, electrical screwdriver and 1 system)			

Assembly Part 1, fictitious created level of automation

AP2 Manufacturing stations / Level of automation	A Stamping Vehicle Identification Number (VIN) (3 times)	B Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	C Fitting gear shift	D Closing bonnet	E Lifting down	F Fitting windscreen 1, Fitting rear glass 1	G Fitting windscreen 2, Fitting rear glass 2	H Fitting side glasses
Level of automation 1 (Golf A5 WOB)	automatic (2 robots and 1 facility)	automatic (18 facilities, 1 robot and 1 lifter)	automatic (1 robot)	automatic (1 robot)	automatic (3 facilities and 1 lifter)	automatic (2 robots)	automatic (2 robots)	automatic (4 robots)
Level of automation 2	manual (3 manipula-tors)	automatic (18 facilities, 1 robot and 1 lifter)	automatic (1 robot)	automatic (1 robot)	automatic (3 facilities and 1lifter)	automatic (2 robots)	automatic (2 robots)	automatic (4 robots)
Level of automation 3	manual (3 manipula-tors)	automatic (18 facilities, 1 robot and 1 lifter)	manual (accu screw-driver)	manual	automatic (3 facilities and 1 lifter)	automatic (2 robots)	automatic (2 robots)	manual (1 robot)
Level of automation 4 (Auto5000 WOB)	manual (3 manipula-tors)	automatic (18 facilities, 1 robot and 1 lifter)	manual (accu screw-drive)	manual	automatic (3 facilities and 1 lifter)	manual (2 robots)		manual (1 robot)
Level of automation 5 (Golf A5 SA)	manual (3 manipula-tors)	manual (3 facilities and 1 lifter)	manual (accu screw-driver)	manual		manual (2 robots)		manual (1 robot)

Assembly Part 2, fictitious created level of automation

AP3	A	B	C	D	E	F	G	H	I	J
Manufacturing stations / Level of automation	Opening bonnet	Putting in/Fitting the CW-trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels
Level of automation 1 (Golf A5 WOB)	automatic (1 facility)	automatic (2 facilities)	automatic (1 robot and 0,5 mani-pulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)
Level of automation 2	manual	manual (accu screw-driver)	automatic (1 robot and 0,5 mani-pulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)
Level of automation 3	manual	manual (accu screw-driver)	automatic (1 robot and 0,5 mani-pulator)	automatic (1 robot)	manual (electrical screwdriver)	manual (accu screw-driver)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)
Level of automation 4	manual	manual (accu screw-driver)	manual (manipulator and accu screwdriver)		manual (electrical screwdriver)	manual (accu screw-driver)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)
Level of automation 5	manual	manual (accu screw-driver)	manual (manipulator and accu screwdriver)		manual (electrical screwdriver)	manual (accu screw-driver)	automatic (1 robot and 1 facility)		manual (manipulator)	manual (2 supporters, accu screw-driver and 2 manipulator)
Level of automation 6 (Auto5000 WOB)	manual	manual (accu screw-driver)	manual (accu screwdriver)		manual (electrical screwdriver)	manual (accu screw-driver)	manual (manipulator with sensors)	manual (accu screw-driver)	manual (manipulator)	manual (2 supporters, accu screw-driver and 2 manipulator)
Level of automation 7 (Golf A5 SA)	manual	manual (accu screw-driver)	manual (accu screwdriver)		manual (electrical screwdriver)	manual (accu screw-driver)	manual (manipulator without sensors)	manual (accu screw-driver)	manual	manual (electrical screwdriver)

Assembly Part 3, fictitious created level of automation

AP1	A	B	C	D	E	F	G	H	I	J	K	L	M
Manufacturing stations / Level of automation	Rollforming tailgate	Fitting cockpit location brackets	Rollforming doors	Cleaning window flange, Closing tailgate	Priming window flange, Opening bonnet	Applying cockpit glue	Cockpit fitting 1	Removing cable box, Remaining screw connections	Remaining screw connections	Cockpit fitting 2	Removing cable box, Remaining screw connections	Remaining screw connections	Total
Level of automation 1 (Golf A5 WOB)	FISeQS (T.C./veh.) 0,00503	FISeQS (T.C./veh.) 0,00003	FISeQS (T.C./veh.) 0,00358	FISeQS (T.C./veh.) 0,00002	FISeQS (T.C./veh.) 0,00051	FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.)				FISeQS (T.C./veh.) 0,01543		FISeQS (T.C./veh.) **0,02484**
Level of automation 2	myprocess (T.C./veh.) 0,00188	FISeQS (T.C./veh.) 0,00003	myprocess (T.C./veh.) 0,00229	FISeQS (T.C./veh.) 0,00002	FISeQS (T.C./veh.) 0,00051	FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.)				FISeQS (T.C./veh.) 0,01543		FISeQS/myprocess (T.C./veh.) **0,02040**
Level of automation 3	myprocess (T.C./veh.) 0,00188	FISeQS (T.C./veh.) 0,00003	myprocess (T.C./veh.) 0,00229	myprocess (T.C./veh.) n. a./n. d.	myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.)				FISeQS (T.C./veh.) 0,01543		FISeQS/myprocess (T.C./veh.) **0,01988**
Level of automation 4 (Auto5000 WOB)	myprocess (T.C./veh.) 0,00188	FISeQS (T.C./veh.) 0,00081	myprocess (T.C./veh.) 0,00229	myprocess (T.C./veh.) n. a./n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.)			myprocess (T.C./veh.) 0,03950			myprocess (T.C./veh.) **0,04449**
Level of automation 5 (Golf A5 SA)	FISeQS (T.C./veh.) 0,05698	FISeQS (T.C./veh.) 0,00081	FISeQS (T.C./veh.) 0,04819	FISeQS (T.C./veh.) n. a./n. d.	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00677							FISeQS (T.C./veh.) **0,11275**

Assembly Part 1, fictitious created level of automation with defects

AP2	A	B	C	D	E	F	G	H	I
Manufacturing stations / Level of automation	Stamping vehicle identification number (VIN) (3 times)	Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	Fitting gear shift	Closing bonnet	Lifting down	Fitting windscreen 1, Fitting rear glass 1	Fitting windscreen 2, Fitting rear glass 2	Fitting side glasses	Total
Level of automation 1 (Golf A5 WOB)	FISeQS (T.C./veh.) 0,00416	FISeQS (T.C./veh.) 0,01030	FISeQS (T.C./veh.) 0,00016	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,01917		FISeQS (T.C./veh.) 0,00390	FISeQS (T.C./veh.) **0,03769**
Level of automation 2	myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,01030	FISeQS (T.C./veh.) 0,00016	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,01917		FISeQS (T.C./veh.) 0,00390	FISeQS/myprocess (T.C./veh.) **0,03353**
Level of automation 3	myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,01030	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,01917		myprocess (T.C./veh.) 0,00293	FISeQS/myprocess (T.C./veh.) **0,03240**
Level of automation 4 (Auto5000 WOB)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00645	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,01392		myprocess (T.C./veh.) 0,00293	myprocess (T.C./veh.) **0,02330**
Level of automation 5 (Golf A5 SA)	FISeQS (T.C./veh.) 0,00920	FISeQS (T.C./veh.) 0,01245	FISeQS (T.C./veh.) 0,00027	FISeQS (T.C./veh.) n. d.		FISeQS (T.C./veh.) 0,00920		myprocess (T.C./veh.) 0,00293	FISeQS (T.C./veh.) **0,03406**

Assembly Part 2, fictitious created level of automation with defects

AP3	A	B	C	D	E	F	G	H	I	J	K
Manufacturing stations / Level of automation	Opening bonnet	Putting in/Fitting the CW trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels	Total
Level of automation 1 (Golf A5 WOB)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00109	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.) 0,00061	FISeQS (T.C./veh.) **0,00737**
Level of automation 2	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00128	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		FISeQS (T.C./veh.) 0,00025	FIS e QS (T.C./veh.) 0,00061	FISeQS/myprocess (T.C./veh.) **0,00756**
Level of automation 3	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00128	FISeQS (T.C./veh.) 0,00067		myprocess (T.C./veh.) 0,00142	myprocess (T.C./veh.) 0,01642	FISeQS (T.C./veh.) 0,00379		FISeQS (T.C./veh.) 0,00025	FIS e QS (T.C./veh.) 0,00061	FISeQS/myprocess (T.C./veh.) **0,02446**
Level of automation 4	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00128	myprocess (T.C./veh.) 0,00412		myprocess (T.C./veh.) 0,00142	myprocess (T.C./veh.) 0,01642	FISeQS (T.C./veh.) 0,00379		FISeQS (T.C./veh.) 0,00025	FIS e QS (T.C./veh.) 0,00061	FISeQS/myprocess (T.C./veh.) **0,02790**
Level of automation 5	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00128	myprocess (T.C./veh.) 0,00412		myprocess (T.C./veh.) 0,00142	myprocess (T.C./veh.) 0,01642	FISeQS (T.C./veh.) 0,00379		myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00154	FISeQS/myprocess (T.C./veh.) **0,02857**
Level of automation 6 (Auto5000 WOB)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00128	myprocess (T.C./veh.) 0,00412		myprocess (T.C./veh.) 0,00142	myprocess (T.C./veh.) 0,01642	myprocess (T.C./veh.) 0,00438		myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00154	myprocess (T.C./veh.) **0,02916**
Level of automation 7 (Golf A5 SA)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00027	FISeQS (T.C./veh.) 0,01299		FISeQS (T.C./veh.) 0,00014	FISeQS (T.C./veh.) 0,09285	FISeQS (T.C./veh.) 1,41933		FISeQS (T.C./veh.) 0,01381	FISeQS (T.C./veh.) 0,00352	FISeQS (T.C./veh.) **1,54291**

Assembly Part 3, fictitious created level of automation with defects

Results of actual analysis

Manufacturing stations / Level of automation	FISeQS Assembly Part 1	FISeQS Assembly Part 2	FISeQS Assembly Part 3	Field Data	Audit Ist (Target)	VPC	Direct Runners CP 7 / CP 8	Process Audit
Level of automation (Golf A5 WOB)	0,02484 T.C./veh.	0,03769 T.C./veh.	0,00737 T.C./veh.	0,06030 T.C./veh.	77 (90) Audit Points	3,07 T.C./veh.	48 / 52 %	93 %
Level of automation (Auto5000 WOB)	0,04367 T.C./veh.	0,02330 T.C./veh.	0,02916 T.C./veh.	0,01723 T.C./veh.	98 (113) Audit Points	1,31 T.C./veh.	59/ 94 %	89 %
Level of automation (Golf A5 SA)	0,11275 T.C./veh.	0,03113 T.C./veh.	1,54291 T.C./veh.	0,01829 T.C./veh.	96 (94) Audit Points	2,74 T.C./veh.	78/ 89 %	90 %

(green)	=3 points
(white)	=2 points
(red)	=1 point

Manufacturing stations / Level of automation	FISeQS Assembly Part 1	FISeQS Assembly Part 2	FISeQS Assembly Part 3	Field Data	Audit Ist (Target)	VPC	Direct Runners CP 7 / CP 8	Process Audit	Total points
Level of automation (Golf A5 WOB)	3*3 Points	1*3 Points	3*3 Points	1 Points	3 Points	1 Points	1 1 Points	3 Points	31 Points
Level of automation (Auto5000 WOB)	2*3 Points	3*3 Points	2*3 Points	3 Points	2 Points	3 Points	2 3 Points	1 Points	35 Points
Level of automation (Golf A5 SA)	1*3 Points	2*3 Points	1*3 Points	2 Points	1 Points	2 Points	3 2 Points	2 Points	24 Points

Results of actual Analysis

Volkswagen
Werk Wolfsburg

Prozessschritte Montagen
Produktgruppe A5

Lfd. Nr.	Prozessschritte	Unterprozesse 1	2	3	4	5	6
9.c	**Türen, Klappen** 5 Meisterschaften	Türen Ausbau **(1 M-Mech1 Team 3)**	Türen Einbau, Faltenbalg, Türkompaktstecker **(1 M-WF2 Team18)**	Einstellung, Heck, - Front & Türen. **Halle 12 Ovalband** **(1 M-PWA– AP H.12)**	NA Fahrzeugfinish **(1 M)**	Segmentierte Nacharbeit **(1 M)**	
9.d	**Vormontage Türen** 4 Meisterschaften	Modultürmontage: Verkabelung, Scheiben, Verkleidungen Schließsystem **(2 M-PWK-TC)**	Segmentierte Nacharbeit **(1 M)**	NA Fahrzeugfinish **(1 M)**			
9e	**Schiebedach / Formhimmel** 5 Meisterschaften	Formhimmel, Innenraumbel, Sonnenblende, Haltegriffe **(1M-KB3 Team 8)**	Schiebedach, Einbau und einstellen. **(1M-KB1 Team 4)** **(1 M-WF4 H.12)**	Segmentierte Nacharbeit **(1 M)**	NA Fahrzeugfinish **(1 M)**		
10.	**Elektrik**						
10.a	**Batterie** 4 Meisterschaften	Batteriekonsole & Verkleidung (Batterie anschliesen) **(1M-ZT1 Team 12)** **(1M-WF3 Halle12)**	Einbau Batterie & Vorkommisionierung **PWA - 4** **(1M – Mech. 3)**	Segmentierte Nacharbeit Ladestationen Vor Ort **(1 M)**			
10.b	**Infotainmant**						

GQA - 45
ehartha/prozesschritteA5sortiert

Redaktionsschlu

Sub- processes in assembly for Process Audit p.5, Source: Department GQA – 45, VW Wolfsburg

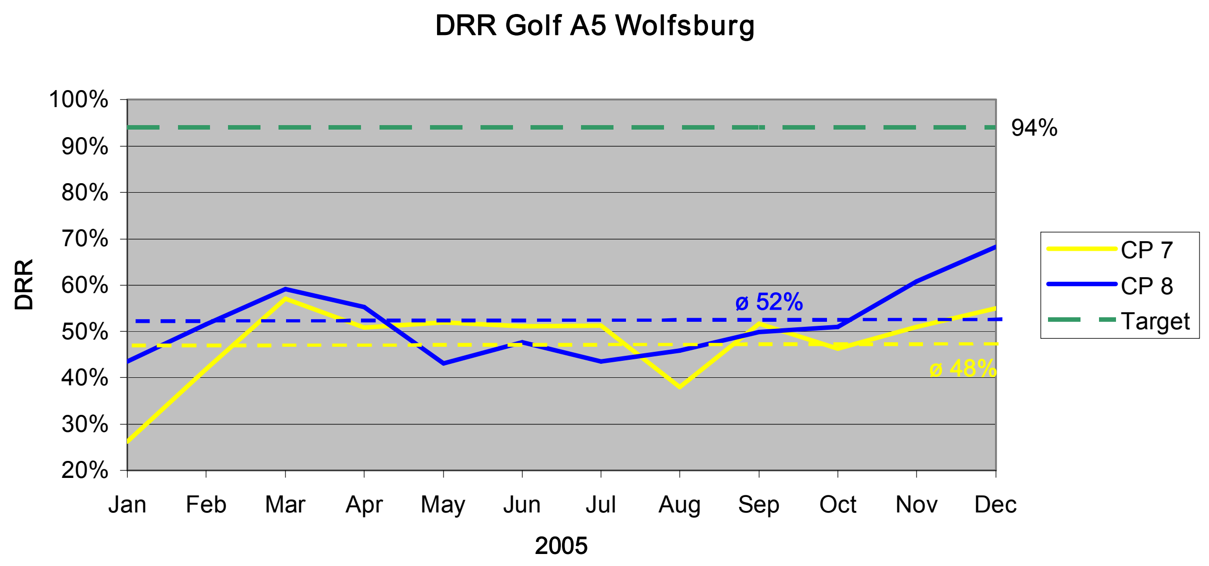
Processaudit

Volkswagen Werk Wolfsburg		**Prozessschritte Montagen Produktgruppe A5**					7. Feb. 06	Seite: 4 von 5
Lfd. Nr.	**Prozessschritte**	**Unterprozesse**						
		1	**2**	**3**	**4**	**5**	**6**	**7**
7.c	**Gurtsysteme** 4 Meisterschaften	Sicherheitsgurte (Gurthöhenverstell.) **(1 M - KB1 Team 5)**	Gurtbeschläge Hinten re / li Funktionsprüfung **(1 M – KB3 Team 8)**	Kommissionierung S – Gurte **(1 M)**	Segmentierte Nacharbeit **(1 M)**			
7.d	**Airbag** 6 Meisterschaften	Airbag – Steuergerät **(1M Vor.KB H.12)**	Kopfairbag **(1 M - KB2 Team 6)**	Lenkrad mittenstellung **(1 M -WF1 Team 16)**	Lenkrad – Airbagmodul **(1M - WF2 Team 18)**	Segmentierte Nacharbeit **(1 M)**	NA Fahrzeugfinish **(1 M)**	
8.	**Klimasystem** 5 Meisterschaften	KML an Exp.-Ventil, KML an Kondensator u. Trockner **(1 M-KB3 Team 9)**	Bef. Klimaleitung Kompressor **(1M-ZT1 Team 12)**	Befüllung Funktionsprüfung-Klimaanlage Schnüffelprobe **(1 M -WF4 H.12)**	Kommissionierung und Segmentierte Nacharbeit **(1 M)**	NA Fahrzeugfinish **(1 M)**		
9.	**Exterieur**							
9.a	**Anbauteile** 8 Meisterschaften	Stoßfänger an Frontend Nacharbeit Lagerung Frontscheinwerfer, Nebelscheinwerfer **(1 M-H.53a)**	Motorabschirmkapse l Frontkl. Dämpf., Radhausschale hinten, Designabdeckung **(1 M-ZT1 Team11)** **(1 M-WF3 H. 12)**	Einbau Frontend **(1 M-Mech.2)**	Front- u. Heck - Wischer Reinigungsanlage, Wasserbehälter, Frontwischermotor Schwellerbeplankung GTI + R32 **(1 M-ZT2 Team 14)** **(1M-KB3 Team 9)**	Segmentierte Nacharbeit **(1 M)**	NA Fahrzeugfinish **(1 M)**	
9.b	**Verglasung** 4 Meisterschaften	Türdichtung, Heckklappendicht. Cockpiteinfahren FR-, SEI-, HECK-Scheiben (Primern) **(1M -Mech1)**	Einbau FR-, SEI-, HECK- Scheiben: **PWA–M4** **(1 M Mech2)**	Kommissionierung Scheiben **(1 M PWL/ZC)**				
GQA - 45 ehartha/prozesschritteA5sortiert							☎ 2 03 19	Redaktionsschluß: 11.01.06

Sub- processes in assembly for Process Audit p.4, Source: Department GQA – 45, VW Wolfsburg

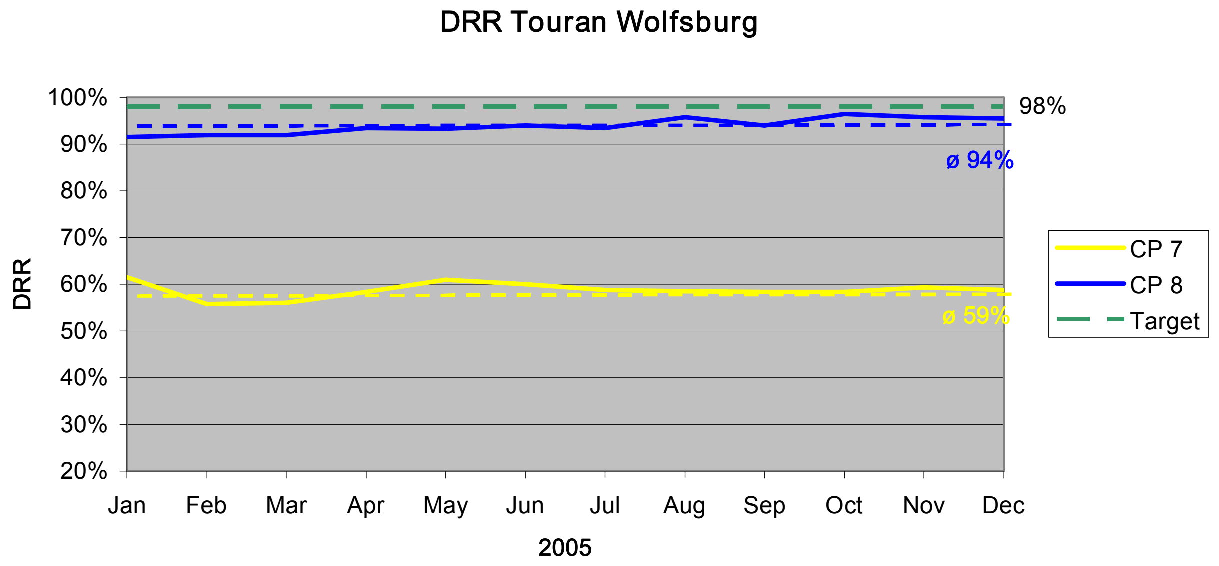
Direct Runner Rate

2005	CP7	CP8	Target
Jan	26%	44%	94%
Feb	42%	52%	94%
Mar	57%	59%	94%
Apr	51%	55%	94%
May	52%	43%	94%
Jun	51%	48%	94%
Jul	51%	44%	94%
Aug	38%	46%	94%
Sep	52%	50%	94%
Oct	46%	51%	94%
Nov	51%	61%	94%
Dec	55%	68%	94%
ø in 2005:	48%	52%	94%



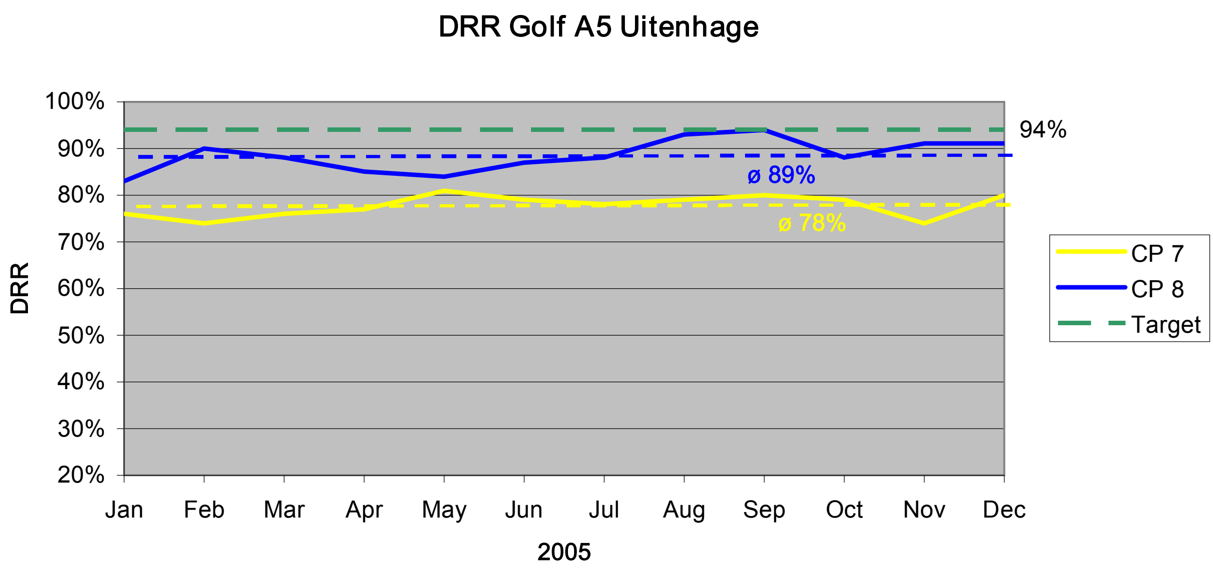
Direct Runner Rate Golf A5 WOB,
Source: Department PWA – S FIS Tagesbericht, VW Wolfsburg

2005	CP7	CP8	Target
Jan	61,5%	91,5%	98%
Feb	55,8%	92,0%	98%
Mar	56,0%	92,0%	98%
Apr	58,3%	93,5%	98%
May	61,0%	93,3%	98%
Jun	60,0%	94,0%	98%
Jul	58,8%	93,5%	98%
Aug	58,5%	95,8%	98%
Sep	58,3%	94,0%	98%
Oct	58,3%	96,5%	98%
Nov	59,3%	95,8%	98%
Dec	58,8%	95,5%	98%
ø in 2005:	**58,7%**	**94,0%**	**98%**

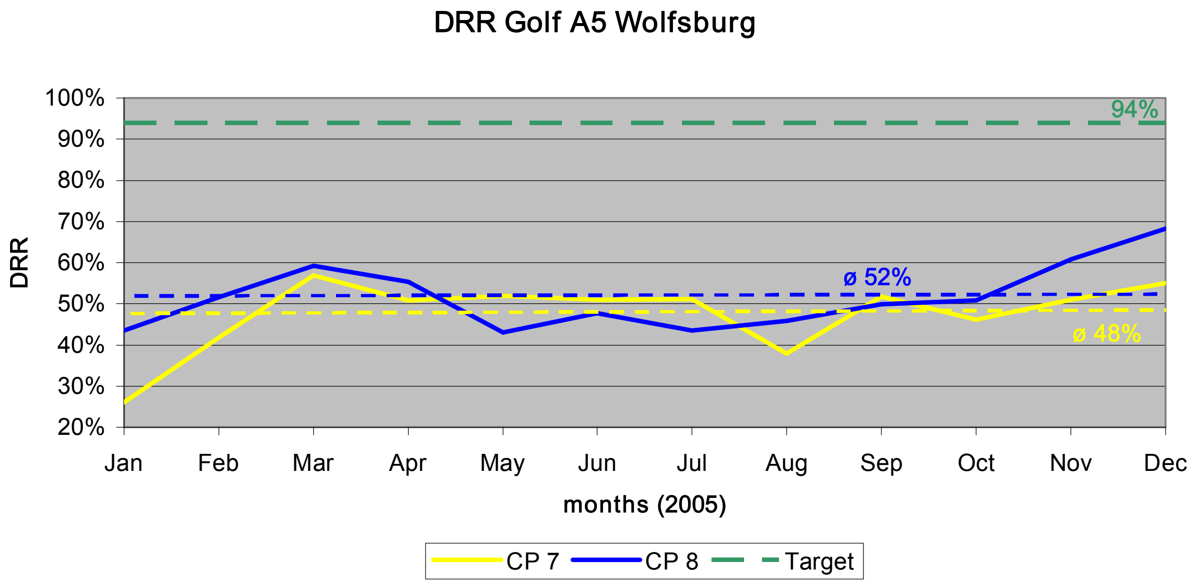


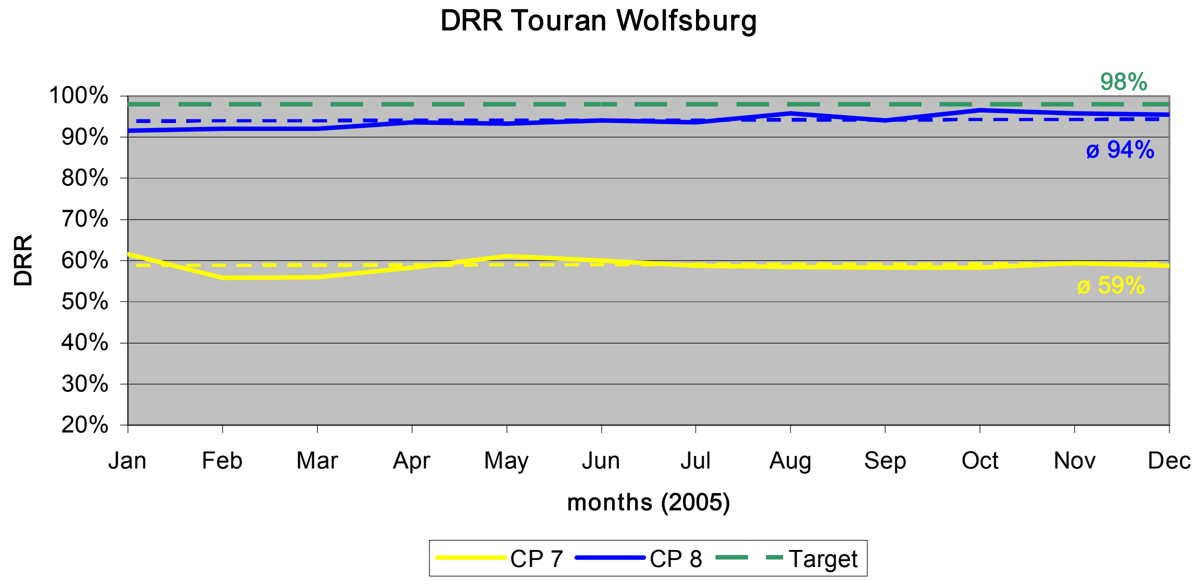
Direct Runner Rate Touran WOB,
Source: Department A5T - FM, Auto5000 Wolfsburg

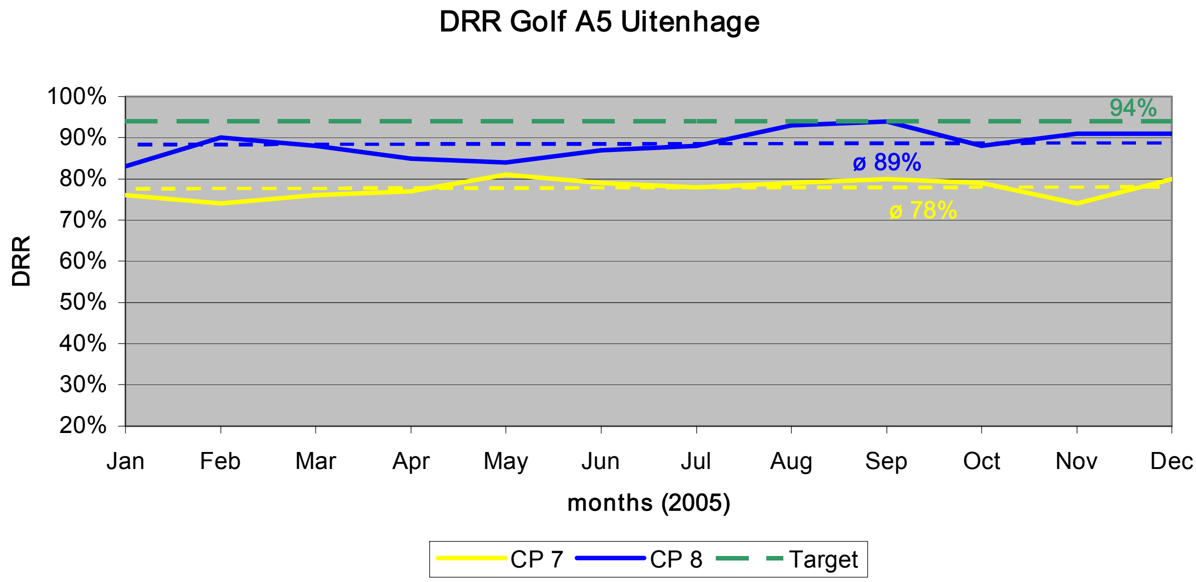
2005	CP 7	CP 8	Target
Jan	76%	83%	94%
Feb	74%	90%	94%
Mar	76%	88%	94%
Apr	77%	85%	94%
May	81%	84%	94%
Jun	79%	87%	94%
Jul	78%	88%	94%
Aug	79%	93%	94%
Sep	80%	94%	94%
Oct	79%	88%	94%
Nov	74%	91%	94%
Dec	80%	91%	94%
ø in 2005:	78%	89%	94%



Direct Runner Rate Golf A5 SA,
Source: Department Quality Assurance Analysis, VW Uitenhage

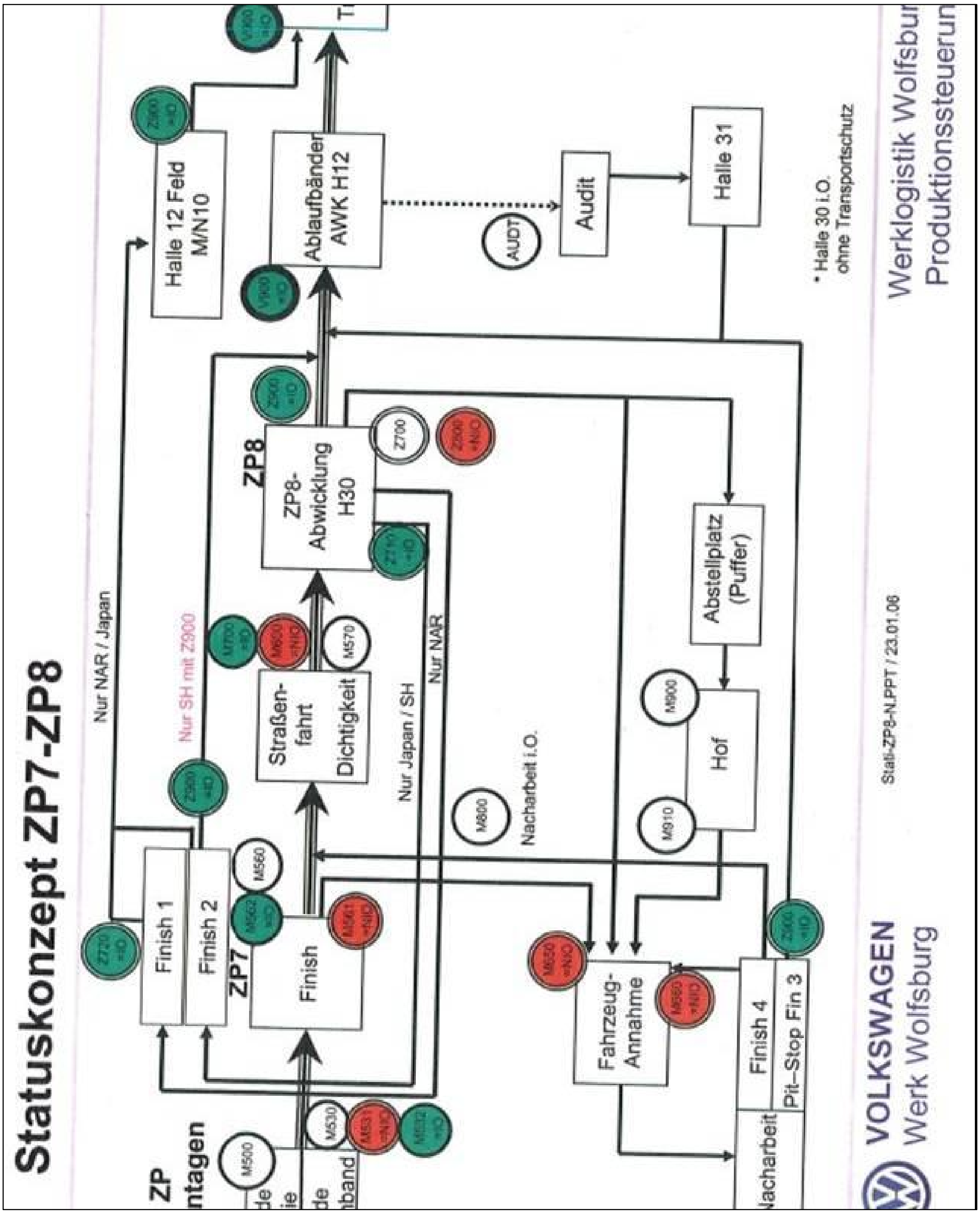






Direct Runner Rates in 2005

Statuskonzepte



Statuskonzept ZP7 – ZP8 Golf A5 WOB,
Source: Department Werklogistik Wolfsburg Produktionssteuerung, VW Wolfsburg

Statusablauf Touran Wolfsburg p.1, Source: Department P – A22, Auto5000 Wolfsburg

Statusablauf Touran Wolfsburg p.2, Source: Department P – A22, Auto5000 Wolfsburg

Statusablauf Touran Wolfsburg p.3, Source: Department P – A22, Auto5000 Wolfsburg

Field-Data

Golf A5 Wolfsburg

Description	trouble case total	Euro per trouble case	Euro total
sealing door o. t. outside front	1655	69,21	114546
cockpit	164	188,12	30851
covering for bumper	109	140,18	15279
vehicle front	82	82,09	6731
alloy wheels	78	296,56	23132
covering for bumper	64	157,83	10101
windscreen tinted	59	258,53	15253
rear	55	253,12	13921
frame	38	203,71	7741
windscreen	37	286,75	10610
wheels	33	154,39	5095
sealing door rear	29	79,22	2298
side window	29	185,79	5388
front spoiler	24	238,03	5713
spoiler rear down	23	277,85	6391
rear screen	21	312,69	6567
resonator	18	120,85	2175
crankcase	16	47,28	756
vehicle rear	16	67,34	1077
fuel tank	14	286,36	4009
housing for gear shift level	13	193,08	2510
wheel fixing	10	15,52	155
wheel fixing lockable	10	5,8	58
suspension for exhaust system	7	48,5	340
gear shift level	6	28,07	168
rear screen tinted	6	224,14	1345
muffler	5	56,27	281
dialling	5	354,61	1773
Total trouble cases	2626	**Sum:**	294.264,00 €
		cost/trouble case:	112,06 €
vehicle in spot check	43546		
trouble cases/vehicle	0,06030	**cost/vehicle (A5 Wolfsburg):**	6,76 €

Table of Field-Data analysis Golf A5 WOB: QUASI FI Top500-Liste VW, Golf Limousine, Wolfsburg of Model Year 2006, Department GQA, VW Wolfsburg

Touran Wolfsburg

Description	trouble case total	Euro per trouble case	Euro total
cockpit	221	148,8	32.885
covering for bumper	34	99,22	3373
wheel	33	62,98	2078
alloy wheel	27	213,84	5774
wheel	25	30,33	758
vehicle front	24	89,36	2145
windscreen	23	311,02	7153
covering for bumper	20	102,68	2054
fuel tank	17	237,07	4030
sealing door o. t. outside front	16	83,82	1341
sealing door rear	16	69,84	1118
windscreen	15	366,21	5493
crankcase	12	50,86	610
resonator	12	76,05	913
rear	11	145,46	1600
rear screen	11	298,07	3279
side window	9	203,64	1833
windscreen	8	287,45	2300
spoiler rear down	8	116,93	935
corner side window rear	7	88,81	622
housing for gear shift level	7	425,06	2975
wheel fixing lockable	7	9,01	63
rear window tinted	7	284,22	1990
dailling	6	650,82	3905
suspension for exhaust system	5	21,69	108
vehicle rear	5	53,69	268
muffler	3	146,86	441
Total trouble cases	589	Sum:	90.044,00 €
		cost/trouble case:	152,88 €
vehicle in spot check	34178		
trouble cases/vehicle	0,01723	cost/vehicle (Touran):	2,63 €

Table of Field-Data analysis Touran WOB: QUASI FI Top500-Liste VW, Touran, Wolfsburg (Auto5000) of Model Year 2006, Department GQA, VW Wolfsburg

Golf A5 Uitenhage

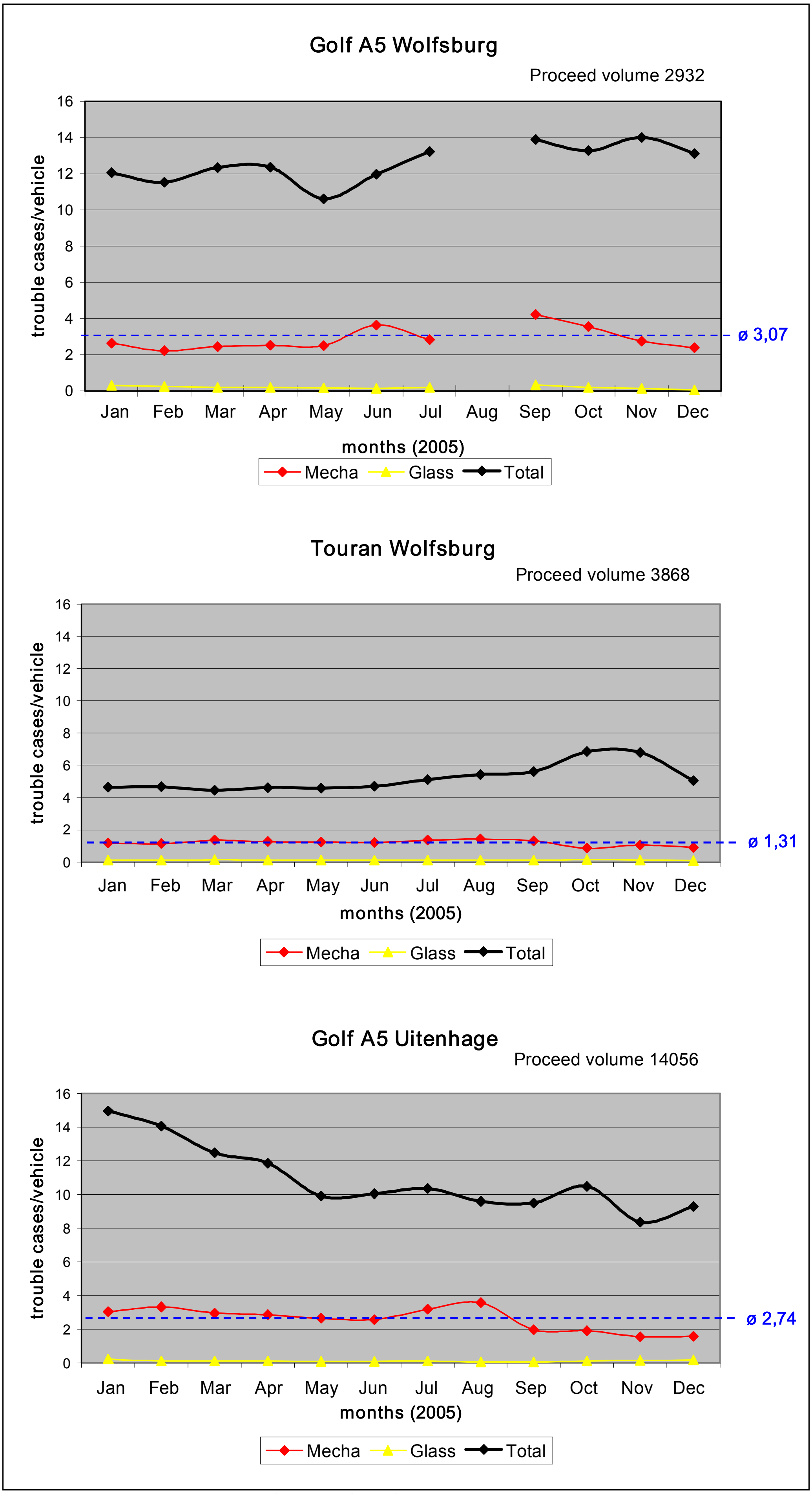
Description	trouble case total	Euro per trouble case	Euro total
windscreen tinted	104	200,75	20878
dash panel	100	159,99	15999
rear door seal	90	71,08	6397
wheel (alloy)	61	203,63	12422
rear bumper cover	31	36,24	1123
lockable wheel fasteners	25	12,97	324
wheel (alloy)	25	38,57	964
selector lever housing	19	360,4	6848
vehicle front	15	48,45	727
tailgate seal	14	55,65	779
front bumper cover	14	85,95	1203
rear silencer	12	71,76	861
front door seal	12	53,62	643
front silencer	10	79,87	799
fuel tank	8	214,65	1717
rear corner window	7	72,62	508
gear lever housing	6	294,2	1765
wheel fasteners	6	9,13	55
temporary spare wheel	5	25,93	130
rear window tinted	5	118,18	591
rear spoiler under	5	84,75	424
exhaust system suspension	3	24,85	75
Total trouble cases	**577**	**Sum:**	**75.232,00 €**
		cost/trouble case:	**130,38 €**
vehicle in spot check	**31549**		
trouble cases/vehicle	**0,01829**	**cost/vehicle (A5 Uitenhage):**	**2,38 €**

Table of Field-Data analysis Golf A5 SA: QUASI FI Top500-Liste VW, Golf Limousine, Uitenhage of Model Year 2006, Department Quality Assurance Analysis, VW Uitenhage

VPC results

VW Wolfsburg Golf A5 2932 units in 2005													in 2005
Processed Volume	413	796	960	330	280	36	22		28	11	24	32	2932
Trouble cases/unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	∅ 2005
Mecha	2,63	2,21	2,45	2,51	2,50	3,64	2,82		4,21	3,55	2,75	2,38	2,88
Glass	0,29	0,24	0,20	0,19	0,16	0,14	0,18		0,32	0,18	0,13	0,06	0,19
Total	**12,05**	**11,53**	**12,35**	**12,36**	**10,62**	**11,98**	**13,22**		**13,89**	**13,27**	**14,01**	**13,12**	**12,58**
Auto 5000 Golf Touran 3868 units in 2005													in 2005
Processed Volume	333	501	674	512	433	440	253	118	193	110	167	134	3868
Trouble cases/unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	∅ 2005
Mecha	1,17	1,14	1,35	1,26	1,24	1,22	1,35	1,42	1,31	0,86	1,05	0,91	1,19
Glass	0,12	0,11	0,14	0,13	0,11	0,11	0,11	0,11	0,12	0,15	0,13	0,08	0,12
Total	**4,63**	**4,66**	**4,45**	**4,62**	**4,59**	**4,69**	**5,11**	**5,43**	**5,61**	**6,84**	**6,79**	**5,05**	**5,21**
VW South Africa Golf 14056 units in 2005													in 2005
Processed Volume	489	786	973	950	1037	1896	1728	1432	1092	1227	1212	1234	14056
Trouble cases/unit	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	∅ 2005
Mecha	3,04	3,34	2,98	2,87	2,66	2,59	3,19	3,59	1,98	1,93	1,57	1,59	2,61
Glass	0,24	0,13	0,14	0,12	0,1	0,11	0,12	0,07	0,07	0,13	0,16	0,18	0,13
Total	**14,96**	**14,06**	**12,47**	**11,86**	**9,91**	**10,05**	**10,36**	**9,6**	**9,51**	**10,49**	**8,37**	**9,3**	**10,91**

Table of VPC analysis: VPC report of 2005, Department P2Q, VW Wolfsburg



Charts of VPC results in 2005

Audit results

Vehicle Audit (assembly) - Analysis 2005 Golf A5 Wolfsburg												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Trouble cases per vehicle (2 door car)												
Trouble cases B_{2i}	0,67	0,38	0,38	0,45	0,38	0,53	0,50	0,64	0,38	0,56	0,60	0,20
Trouble cases C_{2i}	5,08	5,23	4,46	5,36	6,08	4,67	4,67	5,27	4,69	4,88	4,60	4,70
Tests n_2	12	13	13	11	13	15	12	11	16	16	20	10
Trouble cases per vehicle (4 door car)												
Trouble cases B_{4i}	0,31	0,40	0,47	0,00	0,92	0,36	0,70	0,20	0,56	0,39	0,58	0,42
Trouble cases C_{4i}	6,08	4,50	4,20	4,27	5,00	5,00	3,70	4,60	4,28	3,72	3,47	5,17
Tests n_4	13	10	15	11	12	14	10	10	18	18	19	12
Trouble cases per vehicles on average (2 and 4 door cars)												
∅ Trouble case $B_{\varnothing i}$	**0,48**	**0,39**	**0,43**	**0,23**	**0,64**	**0,45**	**0,59**	**0,43**	**0,48**	**0,47**	**0,59**	**0,32**
$B_{\varnothing i} = \frac{B_{2i} \cdot n_{2i} + B_{4i} \cdot n_{4i}}{n_{2i} + n_{4i}}$												
∅ Trouble case $C_{\varnothing i}$	**5,60**	**4,91**	**4,32**	**4,82**	**5,56**	**4,83**	**4,23**	**4,95**	**4,47**	**4,27**	**4,05**	**4,96**
$C_{\o i} = \frac{C_{2i} \cdot n_{2i} + C_{4i} \cdot n_{4i}}{n_{2i} + n_{4i}}$												
Total Audit Points per vehicle												
2 door car	87,5	82,3	74,6	84,5	93,8	81,3	80,8	92,7	72,5	81,9	78,0	63,0
4 door car	93,1	70,0	71,3	57,3	95,8	80,0	70,0	65,0	68,3	63,3	66,3	74,2
Average $A_{2,4i}$	90,3	76,15	72,95	70,9	94,8	80,65	75,4	78,85	70,4	72,6	72,15	68,6
ø in 2005: 77,0												
Audit Points B_{APi}, C_{APi} per vehicle												
B_{APi}	**14,48**	**11,66**	**12,85**	**6,75**	**19,18**	**13,44**	**17,73**	**12,91**	**14,26**	**14,10**	**17,71**	**9,60**
$B_{APi} = 30 \cdot B_{\o i}$												
C_{APi}	**75,82**	**64,49**	**60,10**	**64,15**	**75,62**	**67,21**	**57,67**	**65,94**	**56,14**	**58,50**	**54,44**	**59,00**
$C_{APi} = A_{2,4i} - B_{APi}$												

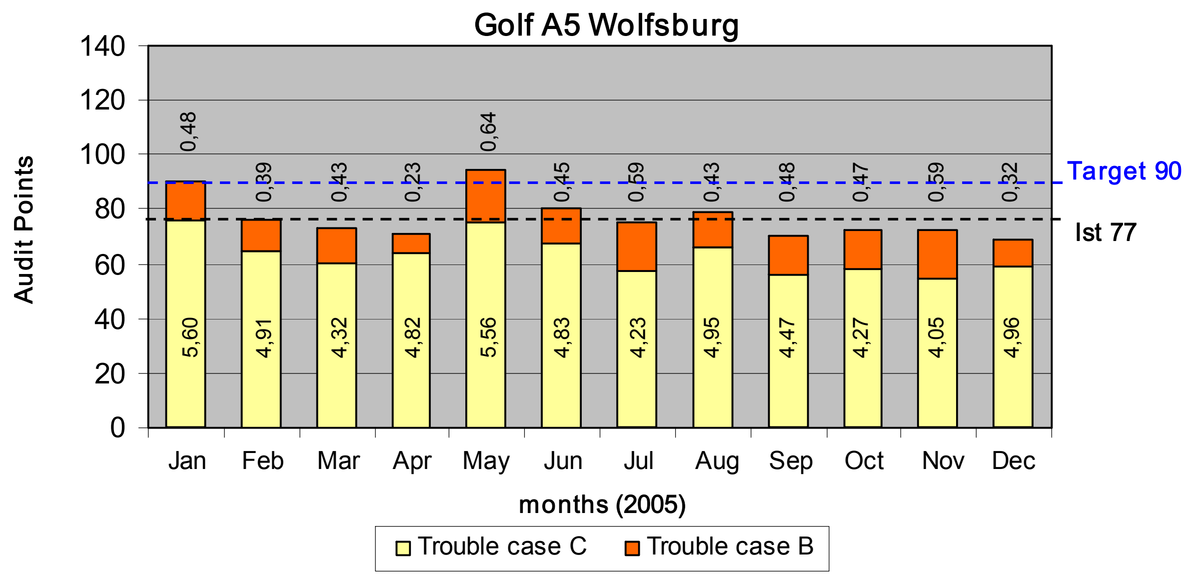
Table of Vehicle-Audit analysis Golf A5 WOB, Source: Audit reports of 2005, Department PWA – K/E, VW Wolfsburg

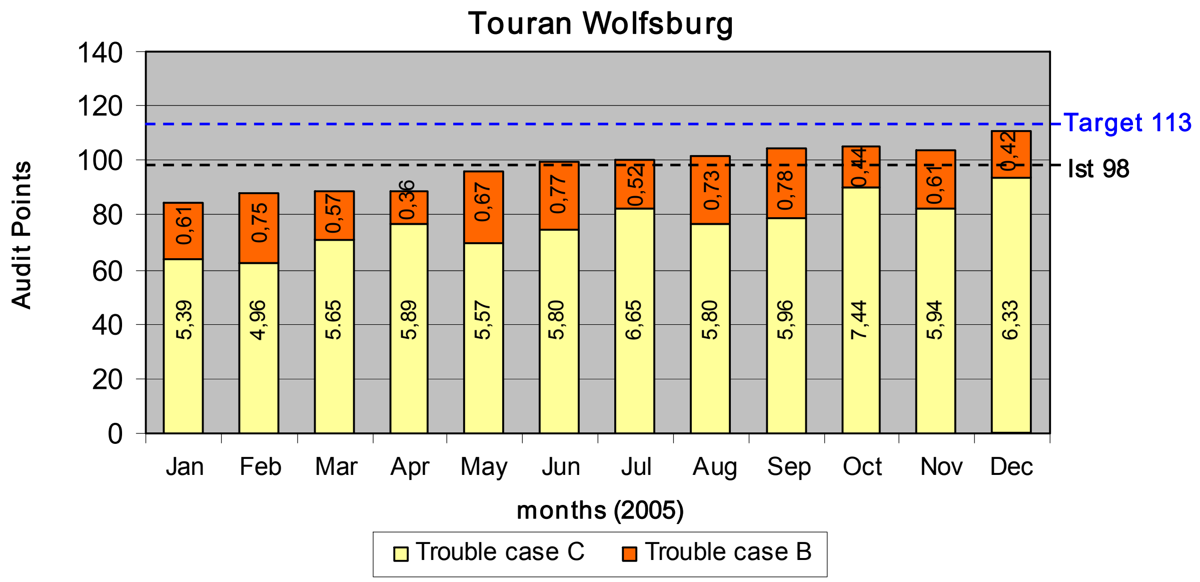
Vehicle Audit (assembly) - Analysis 2005 Touran Wolfsburg												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Trouble cases per vehicle												
Trouble cases B	0,61	0,75	0,57	0,36	0,67	0,77	0,52	0,73	0,78	0,44	0,61	0,42
Trouble cases C	5,39	4,96	5,65	5,89	5,57	5,80	6,65	5,80	5,96	7,44	5,94	6,33
Tests n	18	28	23	36	30	34	23	15	23	18	18	11
Total Audit Points per vehicle												
Average A_i	84,45	87,86	89,13	89,16	95,67	99,66	100,00	101,34	104,78	105,00	103,33	110,91
ø in 2005:	97,6											
Audit Points B_{APi}, C_{APi}												
B_{APi}	**20,56**	**25,00**	**18,26**	**12,22**	**26,00**	**25,33**	**17,39**	**24,67**	**25,65**	**15,00**	**21,22**	**17,27**
$B_{APi} = 30 \cdot B_{øi}$												
C_{APi}	**63,89**	**62,86**	**70,87**	**76,94**	**69,67**	**74,33**	**82,61**	**76,67**	**79,13**	**90,00**	**82,22**	**93,64**
$C_{APi} = A_i - B_{APi}$												

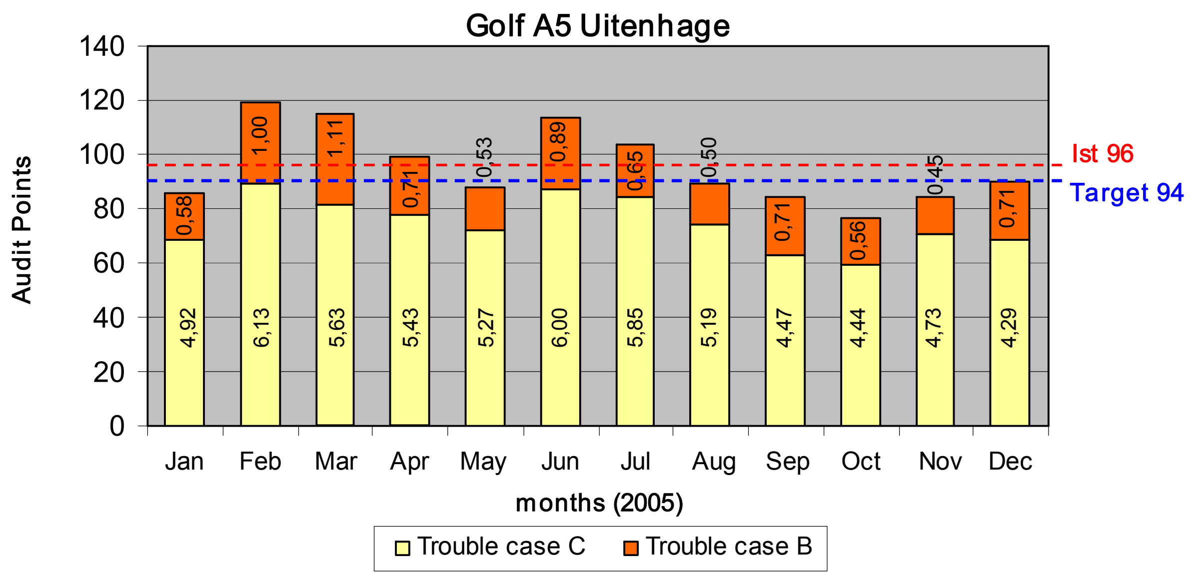
Table of Vehicle-Audit analysis Touran WOB, Source: Audit reports of 2005,
Department A5T - FM, Auto5000 Wolfsburg

Vehicle Audit (assembly) - Analysis 2005 Golf A5 Uitenhage												
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Trouble cases per vehicle												
Trouble cases B	0,58	1,00	1,11	0,71	0,53	0,89	0,65	0,50	0,71	0,56	0,45	0,71
Trouble cases C	4,92	6,13	5,63	5,43	5,27	6,00	5,85	5,19	4,47	4,44	4,73	4,29
Tests n	12	15	19	14	15	19	20	16	17	16	11	7
Total Audit Points per vehicle												
Average A_i	85,8	119,3	114,7	99,3	88,0	113,7	103,5	89,4	84,1	76,3	84,5	90,0
ø in 2005:	95,7											
Audit Points B_{APi}, C_{APi}												
B_{APi}	**17,40**	**30,00**	**33,30**	**21,30**	**15,90**	**26,70**	**19,50**	**15,00**	**21,30**	**16,80**	**13,50**	**21,30**
$B_{APi} = 30 \cdot B_{øi}$												
C_{APi}	**68,40**	**89,30**	**81,40**	**78,00**	**72,10**	**87,00**	**84,00**	**74,40**	**62,80**	**59,50**	**71,00**	**68,70**
$C_{APi} = A_i - B_{APi}$												

Table of Vehicle-Audit analysis Golf A5 SA, Source: Audit reports of 2005,
Department Final Vehicle Audit, VW Uitnehage





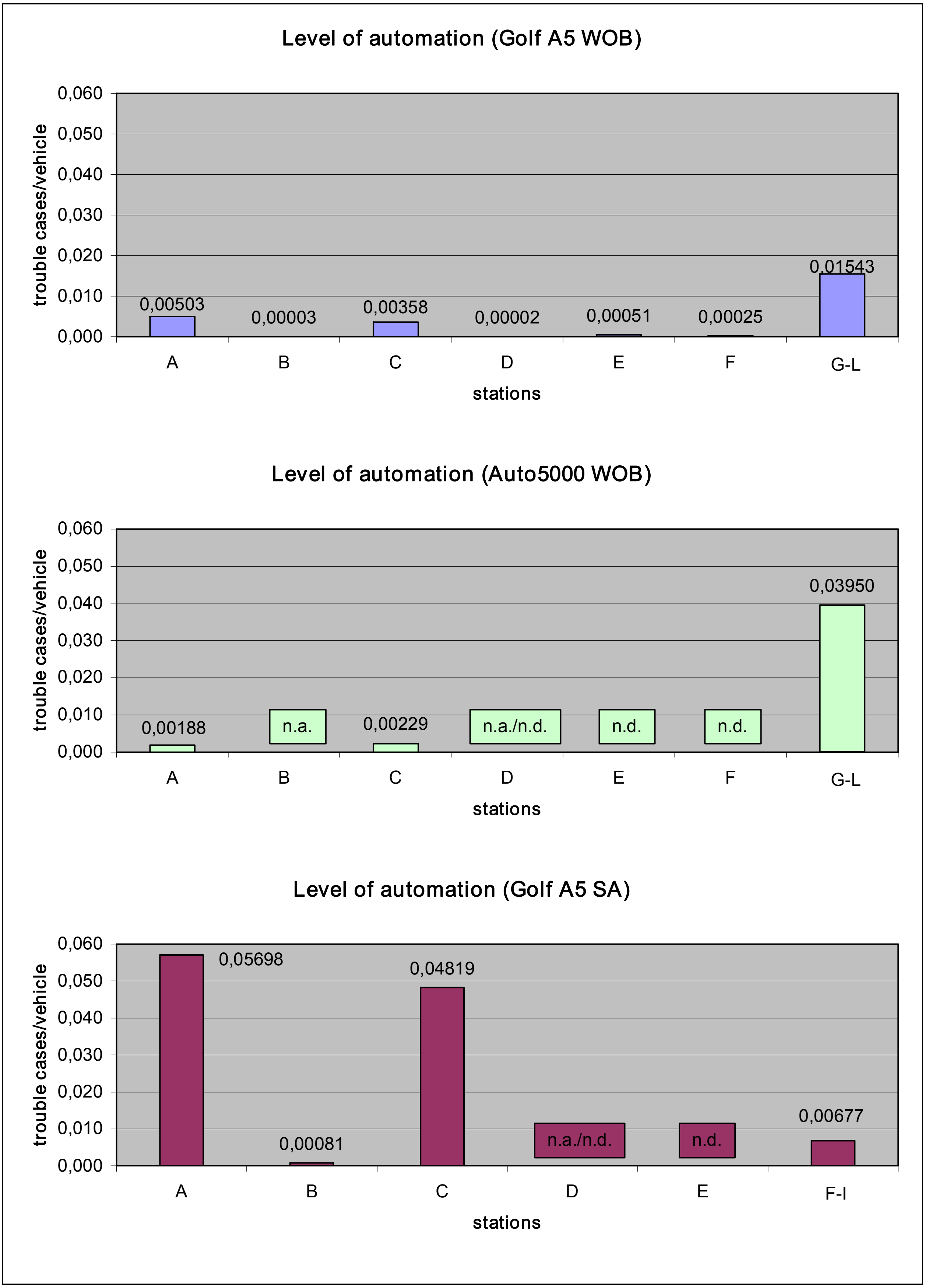


Charts of Vehicle-Audit results in 2005

Matrixes and Charts of Assembly Parts with defects

AP1	Manufacturing stations / Level of automation	Level of automation (Golf A5 WOB)	Level of automation (Auto5000 WOB)	Level of automation (Golf A5 SA)
A	Rollforming tailgate	FISeQS (T.C./veh.) 0,00503	myprocess (T.C./veh.) 0,00188	FISeQS (T.C./veh.) 0,05698
B	Fitting cockpit location brackets	FISeQS (T.C./veh.) 0,00003	myprocess (T.C./veh.) n. a.	FISeQS (T.C./veh.) 0,00081
C	Rollforming doors	FISeQS (T.C./veh.) 0,00358	myprocess (T.C./veh.) 0,00229	FISeQS (T.C./veh.) 0,04819
D	Cleaning window flange, Closing tailgate	FISeQS (T.C./veh.) 0,00002	myprocess (T.C./veh.) n. a./n. d.	FISeQS (T.C./veh.) n. a./n. d.
E	Priming window flange, Opening bonnet	FISeQS (T.C./veh.) 0,00051	myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) n. d.
F	Applying cockpit glue	FISeQS (T.C./veh.) 0,00025	myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00677 (F–I)
G	Cockpit fitting 1	FISeQS (T.C./veh.)	myprocess (T.C./veh.) (G–I)	(cont.)
H	Removing cable box, Remaining screw connections		(cont.)	(cont.)
I	Remaining screw connections		(cont.)	(cont.)
J	Cockpit fittting 2		myprocess (T.C./veh.) 0,03950 (J–L)	
K	Removing cable box, Remaining screw connections	FISeQS (T.C./veh.) 0,01543	(cont.)	
L	Remaining screw connections		(cont.)	
M	Total	FISeQS (T.C./veh.) 0,02484	myprocess (T.C./veh.) 0,04367	FISeQS (T.C./veh.) 0,11275

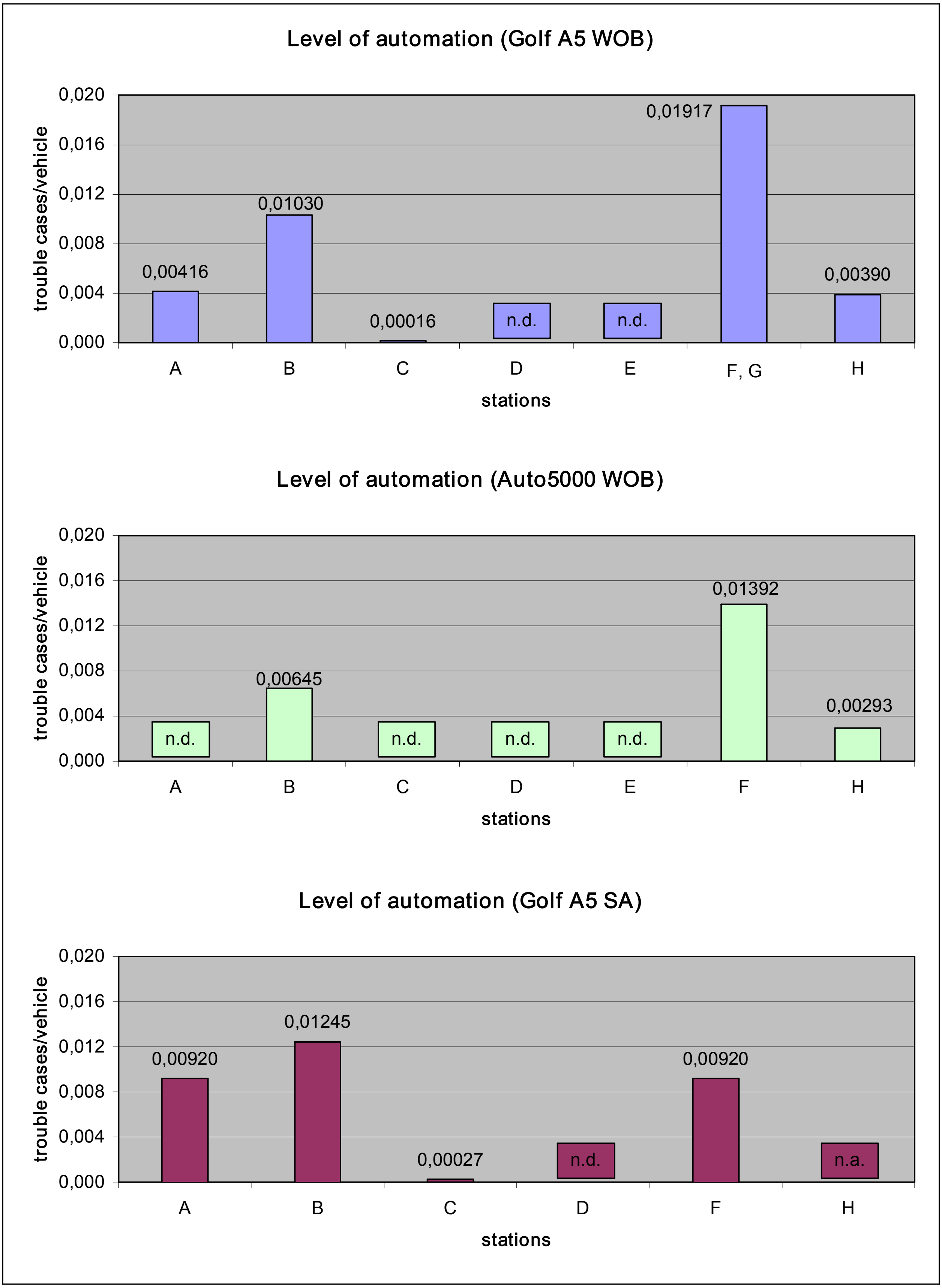
Assembly Part 1, matrix with defects per step and vehicle



Assembly Part 1, charts of defects per station

AP2	A	B	C	D	E	F	G	H	I
Manufacturing stations / Level of automation	Stamping vehicle identification number (VIN) (3 times)	Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	Fitting gear shift	Closing bonnet	Lifting down	Fitting windscreen 1, Fitting rear glass 1	Fitting windscreen 2, Fitting rear glass 2	Fitting side glasses	Total
Level of automation (Golf A5 WOB)	FISeQS (T.C./veh.) 0,00416	FISeQS (T.C./veh.) 0,01030	FISeQS (T.C./veh.) 0,00016	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,01917		FISeQS (T.C./veh.) 0,00390	FISeQS (T.C./veh.) **0,03769**
Level of automation (Auto5000 WOB)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00645	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,01392		myprocess (T.C./veh.) 0,00293	myprocess (T.C./veh.) **0,02330**
Level of automation (Golf A5 SA)	FISeQS (T.C./veh.) 0,00920	FISeQS (T.C./veh.) 0,01245	FISeQS (T.C./veh.) 0,00027	FISeQS (T.C./veh.) n. d.		FISeQS (T.C./veh.) 0,00920		FISeQS (T.C./veh.) n. a.	FISeQS (T.C./veh.) **0,03113**

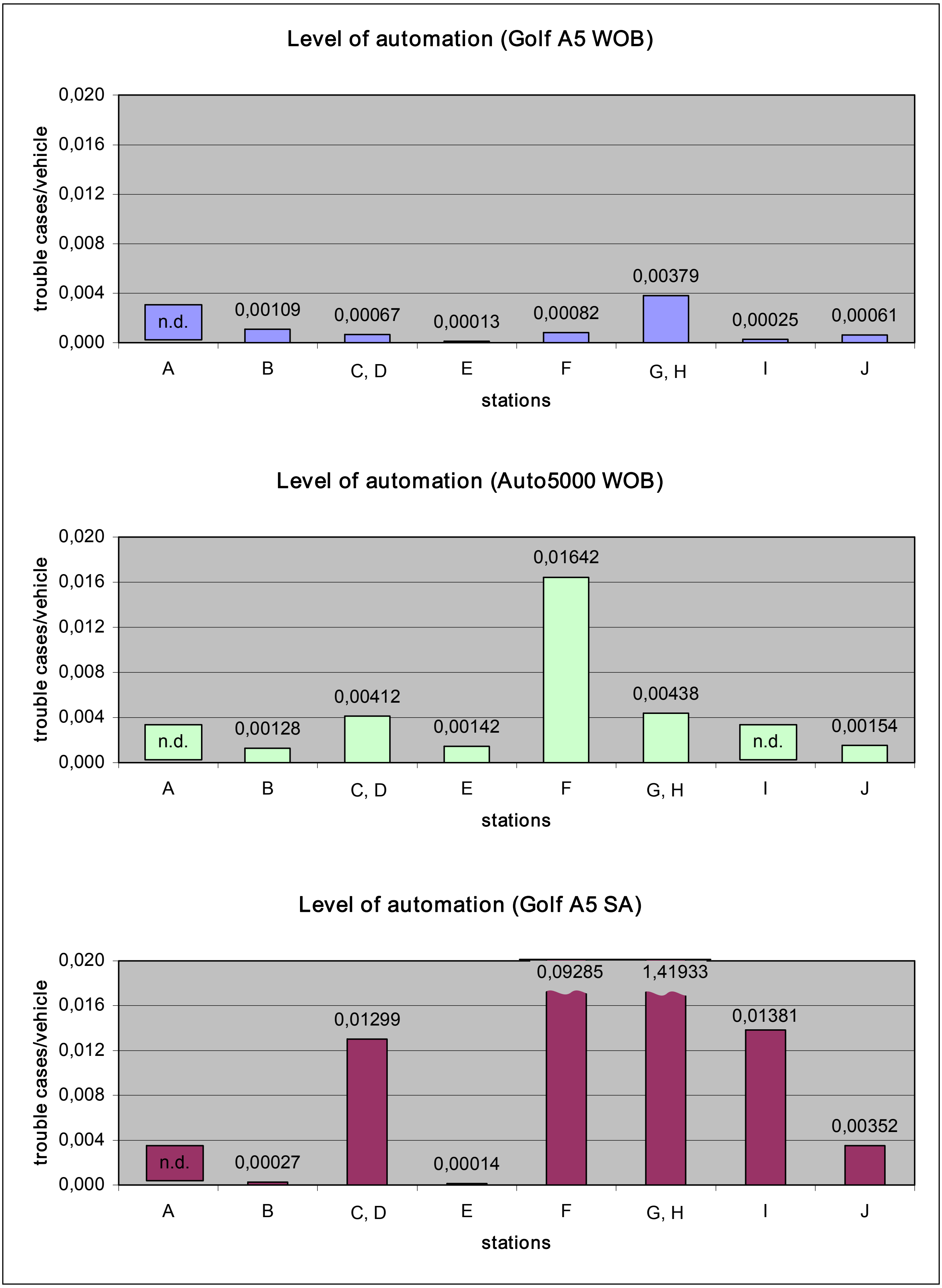
Assembly Part 2, matrix with defects per step and vehicle



Assembly Part 2, charts of defects per station

AP3	A	B	C	D	E	F	G	H	I	J	K
Manufacturing stations / Level of automation	Opening bonnet	Putting in/Fitting the CW trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels	Total
Level of automation (Golf A5 WOB)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00109	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.) 0,00061	FISeQS (T.C./veh.) **0,00737**
Level of automation (Auto5000 WOB)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00128	myprocess (T.C./veh.) 0,00412		myprocess (T.C./veh.) 0,00142	myprocess (T.C./veh.) 0,01642	myprocess (T.C./veh.) 0,00438		myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00154	myprocess (T.C./veh.) **0,02916**
Level of automation (Golf A5 SA)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00027	FISeQS (T.C./veh.) 0,01299		FISeQS (T.C./veh.) 0,00014	FISeQS (T.C./veh.) 0,09285	FISeQS (T.C./veh.) 1,41933		FISeQS (T.C./veh.) 0,01381	FISeQS (T.C./veh.) 0,00352	FISeQS (T.C./veh.) **1,54291**

Assembly Part 3, matrix with defects per step and vehicle



Assembly Part 3, charts of defects per station

Produced units in 2005 (Golf A5 WOB and Auto5000)

Number per vehicles per month (2005)			
Months	**Assembly part 1**	**Assembly part 2**	**Assembly part 3**
Jan.	15139	15163	15092
Feb.	12420	12381	12467
Mar.	15112	15186	15138
Apr.	16753	16819	16725
May	12711	12730	12776
Jun.	18515	18561	18559
Jul.	10679	10674	10686
Aug.	9363	9372	9051
Sep.	15305	15297	15146
Oct.	13536	13555	13350
Nov.	14693	14690	15516
Dec.	10487	10475	10478
Total	**164713**	**164903**	**164984**

Produced units in Golf A5 assembly in each Assembly Part in 2005

Number per vehicles per month (2005)	
Months	**Vehicles**
Jan.	13402
Feb.	17019
Mar.	15029
Apr.	19642
May	17501
Jun.	18807
Jul.	13819
Aug.	9918
Sep.	18752
Oct.	11031
Nov.	18577
Dec.	11873
Total	**185370**

Produced units in Auto5000 assembly in 2005

Manufacturing stations	Description		Total Trouble Cases	Total Trouble Cases/stations
Rollforming tailgate	Sealing for tailgate damaged	A	1	421
	Sealing for tailgate incomplete		4	
	Sealing for tailgate loose		56	
	Sealing for tailgate wavy		322	
	Sealing for tailgate wrong assembled		38	
Fitting cockpit location brackets	Cockpit location brackets wrong assembled	B	6	6
Rollforming doors	Sealing for door damaged	C	51	356
	Sealing for door dirty		4	
	Sealing for door dust left alignment nok		6	
	Sealing for door dust left damaged		1	
	Sealing for door dust left loose		8	
	Sealing for door dust left wrong assembled		32	
	Sealing for door dust right alignment nok		7	
	Sealing for door dust right damaged		2	
	Sealing for door dust right loose		3	
	Sealing for door dust right missing		1	
	Sealing for door dust right wrong assembled		46	
	Sealing for door wavy		51	
	Sealing for door wrong assembled		144	
Cockpit fitting 1, 2	Cockpit alignment nok	F-I	14	50
	Cockpit damaged		19	
	Cockpit dirty		3	
	Cockpit dogleg trim covers		2	
	Cockpit incomplete		6	
	Cockpit wrong assembled		5	
	Cockpit wrong part		1	
Total			833	

Table of assembly defects in each step of AP1 in Golf A5 SA, after Source: Utilisation of Department IS Quality System, VW Uitenhage

Manufacturing stations	Description		Total Trouble Cases	Total Trouble Cases/stations
Stamping vehicle identification number (VIN) (3 times)	Stamping VIN damaged	A	35	68
	Stamping VIN incomplete		15	
	Stamping VIN missing		1	
	Stamping VIN wrong assembled		17	
Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	Axle to body loose	B	2	92
	Engine to underbody incomplete		2	
	Front strut to body incomplete		2	
	Front struts to body loose		4	
	Fuel tank incomplete		6	
	Heatshield panel damaged		2	
	Rear axle stabiliser arm flange incomplete		30	
	Rear shock to upper body incomplete		9	
	Underbody angle torque incomplete		1	
	Underbody angle torque loose		1	
	Underbody angle torque missing		1	
	Upper control arms to body incomplete		32	
Fitting gear shift	Gearbox damaged	C	1	2
	Gearbox wrong part		1	
Fitting windscreen 1, Fitting rear glass 1	Windscreen alignment nok	F	1	68
	Windscreen damaged		3	
	Windscreen dirty		5	
	Windscreen leak		1	
	Windscreen missing		57	
	Windscreen wrong assembled		1	
Total			230	

Table of assembly defects in each step of AP2 in Golf A5 SA, after Source: Utilisation of Department IS Quality System, VW Uitenhage

Manufacturing stations	Description		Total Trouble Cases	Total Trouble Cases/stations
Putting in/Fitting the CW-trim panel	CW-trim panel loose	B	1	2
	CW-trim panel missing		1	
Putting in/Fitting the battery	Battery panel damaged	C, D	4	96
	Battery panel incomplete		4	
	Battery panel loose		69	
	Battery panel missing		11	
	Battery panel wrong assembled		8	
Fitting cross member	Defo-element wrong part	E	1	1
Fitting rear bumper	Rear bumper alignment nok	F	371	686
	Rear bumper damaged		20	
	Rear bumper dirty		1	
	Rear bumper flushness		169	
	Rear bumper gap width nok		93	
	Rear bumper incomplete		1	
	Rear bumper loose		9	
	Rear bumper missing		5	
	Rear bumper scratch		1	
	Rear bumper wrong assembled		2	
	Rear bumper wrong part		14	
Fitting frontend/Fitting front bumper	Front bumper alignment nok	G, H	5526	10486
	Front bumper damaged		49	
	Front bumper dirty		1	
	Front bumper flushness		476	
	Front bumper gap width nok		277	
	Front bumper incomplete		14	
	Front bumper loose		1	
	Front bumper strips missing		123	
	Front bumper wrong assembled		27	
	Front bumper wrong part		8	
	Front grill alignment		2	
	Front grill damaged		16	
	Front grill incomplete		4	
	Front grill loose		1	
	Front grill missing		7	
	Front grill wrong assembled		1	
	Front grill wrong part		9	
	Frontend alignment nok		3616	
	Frontend damaged		9	
	Frontend dirty		1	
	Frontend flushness		92	
	Frontend gap width nok		183	
	Frontend incomplete		3	
	Frontend loose		11	
	Frontend missing		8	
	Frontend wrong part		4	
	Intake pipe air cleaner frontend damaged		3	
	Intake pipe air cleaner frontend loose		10	
	Intake pipe air cleaner frontend missing		2	
	Intake pipe air cleaner frontend wrong assmbled		2	
Placing spare wheel in boot	Spare wheel dirty	I	1	102
	Spare wheel missing		99	
	Spare wheel wrong part		2	
Pre-mounting/Fitting wheel	Front wheel damaged	J	2	26
	Front wheel wrong part		12	
	Rear wheel wrong part		12	
Total			11399	

Table of assembly defects in each step of AP3 in Golf A5 SA, after Source: Utilisation of Department IS Quality System, VW Uitenhage

Manufacturing stations	Description		January	February	March	April	May	June	July	August	September	October	November	December	Total Trouble Cases	Total Trouble Cases/stations
Rollforming tailgate	Sealing for tailgate damaged	A	24	48	41	21	22	37	14	30	36	17	24	18	332	349
	Sealing for tailgate leak		0	0	0	0	0	0	0	0	0	0	1	2	3	
	Sealing for tailgate wavy		0	0	0	0	0	1	2	3	4	2	2	0	14	
Rollforming doors	Sealing for door damaged	C	0	0	0	0	11	40	17	16	12	7	19	15	137	424
	Sealing for door loose		0	0	0	0	208	37	4	23	5	5	2	3	287	
Cockpit fittting 1, 2	Cockpit alignment moved to the bottom left	G-L	0	98	56	34	53	420	68	22	73	7	11	17	859	7323
	Cockpit alignment moved to the bottom right		0	63	116	122	81	88	21	40	323	126	20	79	1079	
	Cockpit alignment moved to the top left		0	8	18	48	33	12	13	12	70	70	66	45	395	
	Cockpit alignment moved to the top left + to the bottom right		0	8	8	6	6	8	9	9	18	9	2	5	88	
	Cockpit alignment moved to the top right		0	109	131	204	257	157	550	33	62	41	149	66	1759	
	Cockpit alignment moved to the top rigth + to the bottom left		0	14	19	7	15	20	47	5	7	3	2	0	139	
	Cockpit alignment to far at the front left		0	28	18	8	7	19	51	15	23	2	1	4	176	
	Cockpit alignment to far at the front left + rear right		0	1	10	3	2	1	6	1	2	1	0	0	27	
	Cockpit alignment to far at the front right		0	5	38	36	29	11	23	19	38	14	10	3	226	
	Cockpit alignment to far rear left		0	18	12	1	23	14	39	39	31	3	3	1	184	
	Cockpit alignment to far rear right		0	6	18	33	21	6	76	30	72	23	12	11	308	
	Cockpit not in the middle position to far left		0	44	21	55	22	128	68	28	81	91	75	46	659	
	Cockpit not in the middle position to far right		0	85	323	102	90	56	99	134	178	38	43	16	1164	
	Cockpit rattles		0	1	2	8	9	4	24	27	27	25	38	32	197	
	Cockpit screwing nok		0	1	8	4	4	7	3	0	9	5	4	5	50	
	Cockpit stressless		0	2	2	4	0	2	0	0	1	1	1	0	13	
Total			24	539	841	696	893	1068	1134	486	1072	490	485	368	8096	

Table of assembly defects in each step of AP1 in 2005 in Auto5000 WOB, Source: My process Berichte, Department P- A22, Auto5000

Manufacturing stations	Description		January	Febuary	March	April	May	June	July	August	September	October	November	December	Total Trouble Cases	Total Trouble Cases/stations
Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	Auxiliary frame front axle screwing nok	B	0	3	8	0	2	3	2	0	0	0	0	0	18	1196
	Damper strut model wrong		0	0	0	0	0	0	0	0	2	0	0	0	2	
	Damper strut screwing nok		0	4	3	9	6	3	5	1	4	1	2	0	38	
	Damper strut wrong assembled		0	0	0	0	0	0	0	0	0	0	1	0	1	
	Engine bearer damaged		0	0	3	1	0	1	1	0	2	1	2	1	12	
	Engine bearer missing		0	0	0	0	0	3	19	41	23	3	37	29	155	
	Engine bearer nok		101	56	0	0	0	0	0	0	0	0	0	0	157	
	Engine bearer screwing nok		0	3	4	9	4	4	4	3	5	6	8	6	56	
	Engine screwing nok		0	0	0	0	0	1	0	1	0	2	0	0	4	
	Filler neck screwing nok		0	0	0	1	3	2	1	4	5	6	4	0	26	
	Front axle screwing nok		0	4	13	9	12	12	4	1	10	9	3	10	87	
	Front axle track not adjustable		0	32	62	33	7	6	4	3	5	6	12	13	183	
	Front axle wrong assembled		0	3	0	0	1	0	0	0	0	0	0	0	4	
	Fuel radiator screwing nok		0	37	4	2	4	1	1	0	0	1	0	0	50	
	Gearbox screwing nok		0	2	8	6	8	8	11	4	4	5	2	3	61	
	Heat shield panel screwing nok		0	0	23	0	0	1	1	0	4	0	0	1	30	
	Rear axle damaged		0	0	3	1	2	4	1	0	3	0	8	3	25	
	Rear axle model wrong		0	0	0	1	11	0	0	1	0	0	1	0	14	
	Rear axle rattles		0	0	0	4	0	0	4	2	2	1	0	1	14	
	Rear axle scratch		0	0	2	0	1	0	0	0	0	0	0	0	3	
	Rear axle screwing nok		0	17	17	9	10	12	5	0	5	1	13	5	94	
	Tank clip nok		0	0	2	1	1	0	1	0	1	0	2	0	8	
	Tank damaged		1	0	0	4	1	1	0	0	2	4	2	1	16	
	Tank function nok		0	0	0	0	1	0	0	0	0	0	0	0	1	
	Tank screwing nok		0	0	0	0	0	0	0	1	3	1	1	1	7	
	Tank strap damaged		0	2	1	0	3	1	0	0	0	0	1	1	9	
	Tank strap loose		0	0	0	0	1	0	0	0	2	0	0	1	4	
	Tank strap missing		0	0	1	0	0	0	2	0	1	0	0	0	4	
	Tank strap screwing nok		0	0	7	3	2	3	3	2	9	6	2	6	43	
	Tank strap wrong assembled		0	1	1	0	0	0	0	0	0	1	0	0	3	
	Transmission bearer screwing nok		0	37	1	4	3	1	5	1	3	2	6	4	67	
Fitting windscreen 1, Fitting rear glass 1,	Rear glass damaged	F	0	5	6	6	5	0	3	7	15	7	7	3	64	2581
	Rear glass dirty		0	3	5	8	6	1	1	3	6	1	2	1	37	
	Rear glass gap width nok		0	0	0	0	2	0	0	1	0	0	0	0	3	
	Rear glass leak		12	16	20	9	20	10	45	64	206	61	143	30	636	
	Rear glass missing		6	48	42	37	14	31	43	43	102	55	48	25	494	
	Rear glass wrong assembled		0	1	3	7	7	2	1	2	3	2	2	0	30	
	Windscreen damaged		0	16	15	23	10	12	9	16	32	18	5	6	162	
	Windscreen dirty		0	0	0	0	0	0	2	6	9	8	5	1	31	
	Windscreen leak		2	0	0	14	4	5	12	7	6	8	125	3	186	
	Windscreen missing		10	84	80	60	41	41	62	72	181	120	83	50	884	
	Windscreen wrong assembled		0	9	5	7	3	10	6	0	3	5	3	3	54	
Fitting side glasses	Side glass alignment nok	H	0	12	5	5	13	10	1	5	8	4	7	7	77	543
	Side glass compound nok		0	0	0	0	0	1	0	1	0	0	0	0	2	
	Side glass glass breakage		0	0	0	4	1	2	4	0	6	1	1	5	24	
	Side glass leak		0	14	2	2	2	4	2	2	4	1	44	4	81	
	Side glass missing		0	1	1	1	4	1	0	98	5	1	10	2	124	
	Side glass model wrong		0	0	0	0	0	0	0	0	3	0	0	2	5	
	Side glass pulled off		1	0	0	0	0	0	0	0	0	0	1	0	2	
	Side glass wrong assembled		0	15	23	28	28	29	18	10	20	29	14	14	228	
Total			133	425	370	308	243	226	283	402	704	377	607	242	4320	

Table of assembly defects in each step of AP2 in 2005 in Auto5000 WOB, Source: My process Berichte, Department P- A22, Auto5000

Manufacturing stations	Description		January	February	March	April	May	June	July	August	September	October	November	December	Total Trouble Cases	Total Trouble Cases/stations
Putting in/Fitting the CW trim panel	CW-trim panel damaged	B	0	0	2	9	0	0	0	3	4	4	0	8	30	238
	CW-trim panel loose		0	0	2	10	20	5	16	24	13	10	5	34	139	
	CW-trim panel missing		0	0	2	3	1	5	0	29	3	2	5	6	56	
	CW-trim panel wrong assembled		0	0	1	0	2	2	2	1	1	2	1	1	13	
Putting in/Fitting the battery	Battery console bolt/thread nok	C, D	3	3	1	11	13	22	4	6	8	6	4	18	99	763
	Battery console missing		0	0	0	1	5	12	0	0	0	0	1	1	20	
	Battery console screwing nok		0	4	4	37	31	45	18	20	24	13	18	25	239	
	Battery damaged		0	1	4	5	2	1	1	1	3	4	0	0	22	
	Battery function nok		2	15	13	21	9	7	2	3	1	4	4	3	84	
	Battery gaiter damaged		0	2	0	4	4	1	1	0	0	0	0	0	12	
	Battery gaiter missing		1	2	5	10	13	12	8	2	9	1	2	2	67	
	Battery missing		0	0	0	0	0	0	1	4	2	0	0	1	8	
	Battery model wrong		0	4	4	4	3	12	5	15	9	3	2	4	65	
	Battery panel damaged		0	0	0	0	1	2	0	0	2	2	3	1	11	
	Battery panel loose		0	0	0	0	0	2	3	2	1	0	1	0	9	
	Battery panel missing		0	0	0	0	10	4	5	2	3	0	3	0	27	
	Battery screwing nok		2	10	9	16	9	17	6	1	5	8	7	10	100	
Fitting cross member	Defo-element alignment nok	E	0	8	16	24	16	27	5	5	19	3	18	12	153	264
	Defo-element rear not snapped into place		0	29	1	1	80	0	0	0	0	0	0	0	111	
Fitting rear bumper	Rear bumper alignment nok	F	0	315	32	49	31	42	21	16	134	41	21	70	772	3044
	Rear bumper bolt/thread nok		0	17	33	36	32	25	45	3	11	15	12	8	237	
	Rear bumper damaged		0	86	113	102	66	105	83	49	169	64	124	63	1024	
	Rear bumper mode wrong		0	7	13	5	20	19	6	8	23	6	12	50	169	
	Rear bumper not snapped into place		0	6	32	20	20	13	11	22	13	9	14	12	172	
	Rear bumper screwing nok		9	56	31	57	65	53	43	12	29	22	18	7	402	
	Rear bumper/fender gap width nok		3	16	4	7	11	16	5	4	167	15	7	13	268	
Fitting frontend/Fitting front bumper	Bonnet connector/bush nok	G, H	1	0	0	0	0	1	0	1	0	0	0	0	3	812
	Bonnet scratch		0	1	0	1	0	1	0	1	1	0	0	0	5	
	Frontend adapter - loose		0	0	0	1	1	0	0	0	0	1	2	0	5	
	Frontend adapter damaged		0	1	1	0	1	0	0	0	1	1	0	1	6	
	Frontend adapter missing		0	1	2	2	1	7	4	3	5	8	5	4	42	
	Frontend adapter model wrong		0	0	0	0	0	1	1	1	0	0	0	1	4	
	Frontend adapter not snapped into place		0	0	0	0	0	1	0	0	0	0	0	1	2	
	Frontend connetion nok		0	1	0	0	0	2	1	0	2	0	2	0	8	
	Frontend damaged		0	3	2	9	6	18	5	4	9	6	5	5	72	
	Frontend function nok		0	0	0	0	0	0	0	0	1	0	0	0	1	
	Frontend missed		0	0	0	2	0	1	0	0	0	1	1	0	5	
	Frontend model wrong		2	13	7	20	10	5	6	3	14	7	9	19	115	
	Frontend screwing nok		0	42	31	42	28	29	25	23	34	22	29	18	323	
	Frontend wrong assembled		0	4	2	4	9	5	2	3	6	2	5	7	49	
	Intake pipe air cleaner frontend damaged		0	1	0	1	2	0	0	1	1	0	1	2	9	
	Intake pipe air cleaner frontend loose		0	1	15	1	1	0	3	2	0	0	1	5	29	
	Intake pipe air cleaner frontend missing		0	1	0	5	1	2	2	3	3	1	7	8	33	
	Intake pipe air cleaner frontend support nok		0	0	0	3	0	3	1	1	0	0	0	1	9	
	Intake pipe air cleaner frontend wrong assembled		0	0	0	0	0	2	0	2	1	1	4	7	17	
	Radiator (frontend) connector/bush nok		0	2	5	1	8	2	3	0	5	1	1	0	28	
	Radiator (frontend) loose		0	0	0	1	1	1	1	1	3	0	4	2	14	
	Radiator (frontend) model wrong		0	0	0	0	1	0	0	1	0	2	5	0	9	
	Radiator (frontend) screwing nok		0	1	0	1	0	0	0	0	0	1	0	1	4	
	Radiator (frontend) wrong assembled		0	0	5	1	5	0	0	1	0	5	2	1	20	
Pre-mounting/Fitting wheel	Wheel bolt anti-theft protected damaged	J	0	0	0	0	0	0	1	0	1	0	0	0	2	285
	Wheel bolt anti-theft protected missing		0	1	1	3	2	4	4	0	2	3	8	2	30	
	Wheel damaged		0	1	3	0	5	11	0	0	2	0	5	4	31	
	Wheel loose		0	0	0	0	0	4	0	0	1	0	0	0	5	
	Wheel model wrong		0	1	3	4	12	3	1	2	9	4	12	9	60	
	Wheel screwing nok		0	14	11	11	9	21	27	10	16	6	0	7	132	
	Wheel wrong assembled		0	3	1	3	6	5	3	0	0	1	2	1	25	
Total			23	673	411	548	573	578	381	295	770	307	392	455	5406	

Table of assembly defects in each step of AP3 in 2005 in Auto5000 WOB, Source: My process Berichte, Department P- A22, Auto5000

Tables of assembly defects in looked at Assembly Parts in each production place

Manufacturing stations	Description		January	February	March	April	May	June	July	August	September	October	November	December	Total Trouble Cases	Total Trouble Cases/stations
Rollforming tailgate	Sealing for tailgate damaged	A	20	13	63	51	42	40	16	9	22	19	28	19	342	829
	Sealing for tailgate faulty		0	4	0	0	0	0	0	0	0	0	0	0	4	
	Sealing for tailgate loose		1	3	24	64	4	9	8	1	1	3	2	0	120	
	Sealing for tailgate rollforming nok		11	24	81	26	48	76	26	22	12	5	13	11	355	
	Tailgate leak		3	1	0	2	1	0	0	1	0	0	0	0	8	
Fitting cockpit location brackets	Cockpit location brackets for carrier loose	B	0	0	1	0	0	2	0	0	0	1	0	0	4	5
	Cockpit location brackets for carrier screwing nok		0	0	0	0	0	0	1	0	0	0	0	0	1	
Rollforming doors	Sealing for door front damaged	C	17	16	33	15	7	14	12	5	21	17	27	20	204	589
	Sealing for door front lies flat/sticks out		1	5	4	3	4	3	0	0	0	0	2	1	23	
	Sealing for door front loose		3	0	0	1	2	2	2	0	0	2	0	0	12	
	Sealing for door front missing		1	0	0	1	3	5	3	0	0	3	0	2	18	
	Sealing for door front rollforming nok		1	0	1	0	0	0	0	0	0	0	0	1	3	
	Sealing for door front shrinked		0	0	1	0	0	0	0	0	0	1	0	0	2	
	Sealing for door front snapped		0	0	0	1	1	2	0	1	0	0	0	1	6	
	Sealing for door front sticked		0	1	2	8	2	6	9	0	1	5	0	0	34	
	Sealing for door front wrong assembled		4	5	4	1	1	1	0	0	0	0	2	48	66	
	Sealing for door rear alignment nok		4	4	0	2	0	0	1	0	0	2	2	0	15	
	Sealing for door rear damaged		6	6	19	12	19	17	11	3	11	6	6	3	119	
	Sealing for door rear lies flat/sticks out		3	3	3	3	0	4	0	0	0	0	0	0	16	
	Sealing for door rear loose		1	1	4	3	2	6	2	0	2	1	2	0	24	
	Sealing for door rear missing		0	1	0	1	0	0	0	0	0	0	0	0	2	
	Sealing for door rear rollforming nok		0	0	0	0	0	0	0	0	0	0	1	0	1	
	Sealing for door rear shrinked		0	1	1	1	0	1	0	0	0	1	0	0	5	
	Sealing for door rear snapped		0	0	1	0	1	0	0	0	0	1	2	0	5	
	Sealing for door rear sticked		1	1	3	1	1	2	1	0	0	0	3	2	15	
	Sealing for door rear wrong assembled		3	3	2	1	2	2	1	0	0	2	2	1	19	
Cleaning window flange, Closing the tailgate	Priming pre-treat missing/to little	D	0	0	1	0	0	1	0	0	1	0	0	0	3	3
Priming the window flange + Opening the bonnet	Tailgate dirty with primer	E	8	18	17	7	6	3	1	0	3	8	9	4	84	84
Applying cockpit glue	Mounting plate cockpit glue compound nok	F	0	5	2	2	4	0	0	0	9	7	10	2	41	41
Cockpit fitting 1, 2	Cockpit flush-mounted nok	G-L	1	0	19	2	0	0	0	0	0	0	0	0	22	2541
	Cockpit gap width nok		7	24	198	212	188	247	82	3	9	10	53	44	1077	
	Cockpit lies flat/sticks out		0	0	2	0	0	5	0	0	0	0	0	0	7	
	Cockpit loose		0	2	0	0	4	2	1	0	1	1	2	0	13	
	Cockpit not snapped into place		0	0	0	0	1	0	0	0	0	0	0	0	1	
	Cockpit retaining nok		0	1	1	0	0	1	0	0	1	1	0	1	6	
	Cockpit screwing nok		1	0	1	0	0	1	0	3	2	0	1	3	12	
	Cockpit wrong adjusted		26	42	4	0	0	0	87	91	267	179	262	89	1047	
	Location stud for cockpit bolt/thread nok		0	1	7	0	5	13	7	7	26	7	1	0	74	
	Mounting plate cockpit damaged		0	0	0	0	0	0	0	0	1	0	0	0	1	
	Mounting plate cockpit grommet assembly nok		0	0	0	0	0	0	1	0	0	0	0	0	1	
	Mounting plate cockpit loose		0	0	0	0	0	0	0	0	2	3	4	0	9	
	Mounting plate cockpit screwing nok		1	15	12	1	0	21	5	1	2	2	5	0	65	
	Mounting plate cockpit wrong assembled		0	0	0	0	1	0	0	0	0	0	0	0	1	
	Report cockpit orientating missing		3	11	18	16	32	13	4	24	18	46	14	6	205	
Total			127	211	529	437	381	499	281	171	412	333	453	258	4092	

Table of assembly defects in each step of AP1 in 2005 in Golf A5 WOB, Source: FISeQS Berichte, Department PWA – M/8, VW Wolfsburg

Manufacturing stations	Description		January	Febuary	March	April	May	June	July	August	September	October	November	December	Total Trouble Cases	Total Trouble Cases/stations
Stamping vehicle identification number (VIN) (3 times)	Stamp for VIN illegible	A	0	0	0	0	0	0	0	0	75	0	0	0	75	686
	Stamp for VIN missing		1	2	2	0	0	5	6	5	6	7	2	1	37	
	Stamping VIN damaged		17	18	67	17	15	14	9	6	18	33	30	16	260	
	Stamping VIN illegible		6	7	10	8	21	13	5	2	7	8	15	16	118	
	Stamping VIN missing		16	18	26	11	27	9	8	4	6	5	28	21	179	
	Stamping VIN wrong		2	0	9	0	3	0	0	0	0	0	3	0	17	
Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	Auxiliary frame loose	B	1	0	1	1	0	5	0	1	6	1	5	1	22	1698
	Auxiliary frame rear bolt/thread nok		0	0	0	0	0	2	0	0	0	0	0	1	3	
	Auxiliary frame rear damaged		0	0	0	0	1	0	0	0	0	0	0	0	1	
	Auxiliary frame rear loose		2	1	6	5	1	5	2	1	1	0	1	0	25	
	Auxiliary frame rear noise		0	0	0	0	0	0	0	0	0	0	0	1	1	
	Auxiliary frame rear screwing nok		2	1	10	3	1	1	0	3	9	3	1	1	35	
	Auxiliary frame screwing nok		1	0	0	2	1	2	0	0	0	4	0	2	12	
	B21-BDL damaged		5	2	1	0	2	5	0	0	1	1	3	2	22	
	B22-BDL damaged		5	3	1	0	3	2	1	1	1	1	0	2	20	
	Crankcase for exhaust gas pipe rear loose		0	1	0	1	0	0	1	0	0	0	3	1	7	
	Engine bearer bolt/thread nok		0	2	1	1	0	0	1	2	1	0	1	0	9	
	Engine bearer bush/thread nok		0	0	0	0	0	0	0	0	1	0	0	0	1	
	Engine bearer damaged		0	0	2	1	0	0	0	0	0	1	5	0	9	
	Engine bearer foreign body		0	1	0	0	2	0	1	0	0	0	0	0	4	
	Engine bearer loose		4	8	6	2	1	1	8	0	9	8	6	3	56	
	Engine bearer screwing nok		9	6	4	2	4	1	1	2	6	15	20	6	76	
	Filler neck ground screwing nok		0	0	2	5	1	4	2	0	1	0	1	0	16	
	Filler neck loose		0	0	9	2	3	3	0	0	0	3	0	0	20	
	Filler neck screwing nok		1	0	3	3	5	6	1	0	7	6	8	8	48	
	Fuel radiator damaged		0	0	0	0	2	0	1	0	0	1	0	0	4	
	Fuel radiator loose		0	0	3	0	12	6	3	2	1	0	0	0	27	
	Fuel radiator missing		1	6	3	4	5	6	2	1	4	1	0	3	36	
	Fuel radiator screwing nok		5	3	2	11	33	21	2	4	2	0	3	5	91	
	Fuel radiator wrong		0	0	0	0	0	0	0	0	0	0	0	1	1	
	Fuel tank loose		3	1	3	7	2	5	1	8	2	5	1	3	41	
	Fuel tank screwing nok		8	17	4	6	6	14	11	16	4	9	6	12	113	
	Link rod for tunnel loose		0	0	0	0	0	0	1	0	0	0	0	0	1	
	Link rod for tunnel screwing nok		0	1	0	2	0	0	1	0	0	0	0	0	4	
	λ-sensor behind catalyst pipe damaged		1	2	2	0	3	1	0	1	0	0	1	3	14	
	NOX-sensor damaged		0	0	0	0	0	2	0	0	0	0	0	0	2	
	NOX-sensor loose		0	1	0	0	0	1	0	0	0	0	0	0	2	
	NOX-sensor screwing nok		0	0	0	0	0	0	0	1	0	0	0	0	1	
	Stamp for completion missing		0	0	0	0	0	0	0	0	0	0	0	0	0	
	Stamp for completion-floor 1 illegible		1	3	2	2	5	4	2	0	0	1	2	1	23	
	Stamp for completion-floor 1 missing		20	21	22	21	24	29	30	16	21	20	21	21	266	
	Strap wrench for fuel tank loose		4	1	1	8	2	2	11	2	6	0	2	0	39	
	Strap wrench for fuel tank missing		0	0	0	0	0	0	1	0	0	0	0	0	1	
	Strap wrench for fuel tank screwing nok		0	0	0	3	2	1	0	0	1	0	0	0	7	
	Strap wrench for fuel tank wrong assembled		0	0	0	0	1	0	0	0	0	0	0	0	1	
	Suspension for middle muffler screwing nok		2	3	0	2	0	2	5	0	2	1	0	0	17	
	Suspension for middle muffler wrong assembled		0	lo0	1	0	0	0	0	0	0	0	0	0	1	
	Suspension for rear muffler damaged		1	0	0	2	3	0	0	0	0	0	0	0	6	
	Suspension for rear muffler loose		4	0	0	1	0	0	3	0	0	6	4	1	19	
	Suspension for rear muffler missing		0	0	0	0	0	0	1	0	0	0	0	0	1	
	Suspension for rear muffler screwing nok		4	4	1	0	0	0	2	0	2	6	8	7	34	
	Suspension for rersonator loose		1	0	0	0	0	11	5	0	0	0	1	3	21	
	Suspension-strut loose		13	17	19	10	8	20	13	20	11	6	3	19	159	
	Suspension-strut mount foreign body		0	1	0	0	0	0	0	0	0	0	0	0	1	
	Suspension-strut screwing nok		18	31	31	12	10	13	22	5	14	35	6	3	200	
	Transmission bearer (TB) loose		1	4	1	1	1	3	1	0	1	0	0	0	13	
	Transmission bearer (TB) nok/without function		0	0	0	0	0	1	0	0	0	0	0	0	1	
	Transmission bearer (TB) screwing nok		5	25	16	9	8	21	12	5	5	9	27	7	149	
	Twist beam rear axle loose		0	0	0	0	1	0	0	0	0	0	0	0	1	
	Twist beam rear axle screwing nok		0	1	3	2	2	2	0	0	1	1	1	1	14	
Fitting gear shift	Gear shift housing/selector housing assembly damaged	C	0	0	1	1	7	1	1	0	3	0	0	0	14	27
	Reverse gear high effort		0	0	0	1	4	0	0	0	0	0	0	0	5	
	Reverse gear sticks		0	0	0	4	4	0	0	0	0	0	0	0	8	
Fitting windscreen 1,2, Fitting rear glass 1,2	Rear glass alignment nok	F, G	0	0	11	3	9	6	0	6	3	3	0	0	41	3161
	Rear glass applying glue nok		1053	0	59	8	16	6	1	2	2	2	0	0	1149	
	Rear glass applying primer nok		0	0	0	0	0	3	0	0	0	1	1	0	5	
	Rear glass damaged		0	0	6	5	13	7	0	0	0	0	0	0	31	
	Rear glass delivery quality nok		0	0	0	0	0	0	0	0	0	0	4	0	4	
	Rear glass dirty		5	7	1	0	0	0	0	0	0	1	0	2	16	
	Rear glass dirty with glue		5	12	1	0	0	0	0	0	0	0	2	2	22	
	Rear glass dirty with primer		0	0	8	14	1	0	0	0	0	0	0	0	23	
	Rear glass fine sealing nok		18	12	2	0	0	0	0	0	0	0	0	0	32	
	Rear glass flush-mounted nok		5	20	6	2	3	1	0	1	3	11	9	1	62	
	Rear glass foreign body		0	0	8	4	0	0	0	0	0	0	0	0	12	
	Rear glass gap width nok		4	21	13	0	4	1	1	1	0	2	8	1	56	
	Rear glass glass breakage		12	7	2	3	1	5	5	3	10	20	17	6	91	
	Rear glass glue compound nok		33	452	51	9	39	6	1	0	3	10	3	5	612	
	Rear glass leak		0	0	15	1	3	0	0	0	0	0	0	0	19	
	Rear glass lies flat/sticks out		0	7	0	0	0	0	0	0	0	2	2	0	11	
	Rear glass loose		0	0	0	0	0	0	0	1	1	0	0	0	2	
	Rear glass missing		1	15	5	4	21	15	5	4	19	34	16	0	139	
	Rear glass moved		0	0	0	0	0	0	0	0	0	0	0	0	0	
	Rear glass moved to the top/to the bottom		0	0	0	0	1	1	0	0	0	0	0	0	2	
	Rear glass noise		0	0	0	0	0	0	0	0	0	0	0	0	0	
	Rear glass scratch		8	15	3	3	7	4	3	0	7	6	9	3	68	
	Rear glass sealing defect spot		63	14	4	1	1	0	0	1	1	1	2	2	90	
	Rear glass spot weld burned out		0	0	0	0	0	0	0	0	0	0	0	0	0	
	Rear glass wrong assembled		0	0	4	1	3	6	0	1	3	3	0	0	21	
	Windscreen alignment nok		0	0	2	2	14	6	0	0	2	1	0	0	27	
	Windscreen applying glue nok		3	1	4	1	4	2	0	1	1	0	4	2	23	
	Windscreen applying primer nok		0	1	0	0	0	0	0	0	0	1	0	0	2	
	Windscreen damaged		0	0	19	12	16	11	0	0	0	0	0	0	58	
	Windscreen delivery quality nok		1	4	1	0	0	0	0	0	0	0	2	2	10	
	Windscreen dirty		7	3	4	0	1	4	3	2	3	2	4	3	36	
	Windscreen dirty with glue		0	1	1	4	5	5	1	0	1	1	0	0	19	
	Windscreen dirty with primer		1	1	0	0	1	3	0	1	0	1	3	0	11	
	Windscreen fine sealing nok		0	0	1	0	0	0	0	0	0	2	4	2	9	
	Windscreen flange mounting nok		0	0	0	0	0	0	0	0	0	1	0	0	1	
	Windscreen flush-mounted nok		20	2	1	6	1	0	2	0	1	3	3	1	40	
	Windscreen foreign body		0	0	2	3	5	0	0	0	0	0	0	1	11	
	Windscreen gab width nok		5	9	5	1	3	0	0	1	0	4	10	7	45	
	Windscreen glass breakage		6	16	4	2	1	2	9	2	4	6	12	8	72	
	Windscreen glue compound nok		2	2	5	6	7	6	9	2	1	7	2	1	50	
	Windscreen leak		0	0	23	6	0	0	0	0	0	0	0	1	30	
	Windscreen lies flat/sticks out		0	2	0	0	0	2	0	0	0	2	4	1	11	
	Windscreen missing		4	8	6	0	21	17	7	0	19	21	14	8	125	
	Windscreen moved		0	0	1	0	0	0	0	0	1	0	0	0	2	
	Windscreen moved to the top/to the bottom		0	0	0	0	0	0	0	0	0	0	0	0	0	
	Windscreen noise		0	0	0	0	4	1	1	0	0	0	0	0	6	
	Windscreen scratch		0	6	1	2	1	1	4	1	1	4	3	3	27	
	Windscreen sealing defect spot		1	0	3	0	3	3	0	2	1	0	5	0	18	
	Windscreen spot weld burned out		0	0	7	1	0	0	0	0	0	1	1	0	10	
	Windscreen wrong assembled		0	0	3	1	3	2	0	0	1	0	0	0	10	
Fitting side glasses	Side window rear alignment nok	H	9	1	41	8	8	2	8	0	2	15	4	3	101	643
	Side window rear applying glue nok		0	6	14	4	2	2	1	1	0	3	2	1	36	
	Side window rear damaged		0	0	0	0	1	0	0	0	0	0	0	0	1	
	Side window rear delivery quality nok		0	0	0	0	0	0	0	0	0	0	1	1	2	
	Side window rear dirty		0	2	3	1	0	2	1	1	1	1	1	1	14	
	Side window rear flush-mounted nok		2	3	3	4	7	4	0	1	0	6	0	3	33	
	Side window rear foreign body		0	0	1	0	0	2	1	0	0	1	0	0	5	
	Side window rear gap width nok		1	1	14	2	4	6	3	0	2	5	1	2	41	
	Side window rear glass breakage		0	0	0	0	0	0	0	0	1	2	0	0	3	
	Side window rear glue compound nok		7	30	9	13	16	23	7	4	10	12	1	6	138	
	Side window rear leak		0	0	9	9	7	0	0	0	0	0	0	0	25	
	Side window rear lies flat/sticks out		0	1	1	1	3	4	0	0	0	3	3	1	17	
	Side window rear loose		1	0	4	2	0	0	2	0	0	1	0	0	10	
	Side window rear missing		1	3	11	2	3	9	5	1	10	8	6	4	63	
	Side window rear scratch		2	2	0	3	3	2	4	0	3	7	3	2	31	
	Side window rear sealing defect spot		0	3	0	0	0	1	0	0	0	0	0	1	5	
	Side window rear sticked		0	0	0	0	0	0	0	0	0	0	0	1	1	
	Side window rear water penetration		0	0	1	0	0	0	0	1	0	0	0	0	2	
	Side window rear wavy		0	3	0	0	0	1	0	0	0	2	0	2	8	
	Side window rear wrong		0	0	5	0	9	0	0	0	0	17	0	0	31	
	Side window rear wrong assembled		1	2	25	3	7	10	2	1	4	7	5	9	76	
Total			1445	907	708	330	518	438	263	150	356	440	389	271	6215	

Table of assembly defects in each step of AP2 in 2005 in Golf A5 WOB, Source: FISeQS Berichte, Department PWA – M/8, VW Wolfsburg

Manufacturing stations	Description		January	February	March	April	May	June	July	August	September	October	November	December	Total Trouble Cases	Total Trouble Cases/stations
Putting in/Fitting the CW-trim panel	CW-trim panel clip nok	B	0	0	0	0	1	3	0	0	0	2	2	0	8	180
	CW-trim panel damaged		2	3	0	1	1	3	1	0	0	1	0	4	16	
	CW-trim panel loose		1	5	6	6	3	8	8	2	8	6	15	11	79	
	CW-trim panel missing		5	4	5	3	7	3	2	3	1	2	0	1	36	
	CW-trim panel screwing nok		0	0	0	0	0	0	0	0	0	0	1	0	1	
	CW-trim panel support nok		0	0	0	13	11	0	0	0	0	0	0	0	24	
	CW-trim panel wrong		0	1	0	1	0	12	0	1	0	0	0	1	16	
Putting in/Fitting the battery	Battery cable damaged	C, D	0	0	0	0	0	0	0	1	0	1	0	1	3	111
	Battery cable installation nok		0	0	0	0	0	1	1	0	3	1	0	0	6	
	Battery damaged		0	3	1	0	2	0	0	1	1	0	0	0	8	
	Battery loose		3	2	5	0	3	1	2	0	3	2	5	11	37	
	Battery missing		0	0	0	0	0	0	0	0	0	3	1	0	4	
	Battery nok/without function		0	0	4	1	2	1	2	0	0	0	0	0	10	
	Battery screwing nok		0	2	1	1	0	3	2	2	2	6	1	1	21	
	Battery support nok		0	0	0	0	0	0	2	2	0	0	0	0	4	
	Battery wrong		4	0	0	0	0	4	0	0	0	0	2	3	13	
	Battery wrong assembled		2	0	0	0	0	1	1	0	0	0	0	1	5	
Fitting cross member	Defo-element rear missing	E	0	2	0	0	0	0	0	0	1	2	3	0	8	22
	Defo-element rear screwing nok		1	0	0	0	0	0	0	0	0	6	5	0	12	
	Defo-element rear wrong		0	0	0	0	0	0	0	0	0	2	0	0	2	
Fitting rear bumper	Rear bumper loose	F	0	0	52	52	0	0	0	0	0	0	0	2	106	135
	Rear bumper screwing nok		0	4	9	1	4	2	0	0	2	2	2	3	29	
Fitting frontend/Fitting front bumper	Front bumper loose	G, H	0	0	41	19	0	0	0	0	0	0	0	0	60	625
	Front bumper screwing nok		0	0	2	1	0	5	0	0	0	0	0	0	8	
	RAB frontend alignment nok		0	0	1	0	0	0	0	0	0	0	0	0	1	
	RAB frontend bush/thread nok		0	0	0	0	0	1	0	1	0	1	0	0	3	
	RAB frontend damaged		17	9	7	11	4	9	5	0	5	9	22	9	107	
	RAB frontend diffrences of colour		0	0	0	0	0	0	0	0	0	0	1	0	1	
	RAB frontend dirty		0	0	1	2	0	0	0	0	0	0	0	0	3	
	RAB frontend flush-mounted nok		1	1	2	2	3	2	3	0	0	3	0	2	19	
	RAB frontend gap width nok		1	0	4	1	5	2	1	3	0	1	0	0	18	
	RAB frontend loose		0	0	5	1	0	0	0	0	0	0	0	0	6	
	RAB frontend missing		0	0	0	1	0	0	0	0	0	0	0	0	1	
	RAB frontend screwing nok		3	1	1	1	1	1	0	0	1	2	3	3	17	
	RAB frontend support nok		0	0	0	0	0	0	1	0	0	0	2	0	3	
	Schottplatte screwing nok		6	15	6	2	4	40	9	5	5	7	8	4	111	
	Stamp for completion-floor 2 illegible		0	4	0	5	7	0	0	0	2	3	2	0	23	
	Stamp for completion-floor 2 missing		16	14	25	21	39	27	16	21	9	28	13	15	244	
Placing spare wheel in boot	Sealing for tailgate sticked	I	0	0	0	0	0	0	0	0	0	2	0	0	2	42
	Spare wheel/space save spare tyre damaged		9	2	0	0	1	1	0	0	3	0	0	0	16	
	Spare wheel/space save spare tyre dirty		0	1	0	0	0	0	0	0	0	0	2	0	3	
	Spare wheel/space save spare tyre loose		0	0	1	1	0	0	0	0	0	0	0	0	2	
	Spare wheel/space save spare tyre missing		0	0	5	0	0	0	0	0	0	0	0	0	5	
	Spare wheel/space save spare tyre scratch		1	0	0	0	0	0	0	0	0	0	0	0	1	
	Spare wheel/space save spare tyre support nok		1	0	0	0	0	0	0	2	0	0	0	0	3	
	Spare wheel/space save spare tyre wrong		0	0	1	0	0	0	0	0	0	0	0	0	1	
	Spare wheel/space save spare tyre wrong assembled		0	0	0	0	0	0	0	0	0	2	6	1	9	
Pre-mounting/Fitting wheel	Adapter for wheel bolt missing	J	0	0	22	19	30	7	0	0	0	0	0	0	78	101
	Adapter for wheel bolt wrong		0	0	1	0	0	0	0	0	0	0	0	0	1	
	Wheel bolt anti-theft protected missing		0	0	2	1	0	1	0	0	0	1	0	3	8	
	Wheel bolt/wheel nut torque bolt/thread nok		0	0	0	0	0	0	0	0	0	0	0	1	1	
	Wheel bolt/wheel nut torque bush/thread nok		0	0	0	0	0	2	0	0	0	0	0	0	2	
	Wheel bolt/wheel nut torque missing		1	0	0	7	0	1	0	0	0	0	0	1	10	
	Wheel bolt/wheel nut torque wrong		0	0	0	0	0	0	0	0	0	1	0	0	1	
Total			74	73	210	174	128	141	56	44	46	96	96	78	1216	

Table of assembly defects in each step of AP3 in 2005 in Golf A5 WOB, Source: FISeQS Berichte, Department PWA – M/8, VW Wolfsburg

Generation and meaning of the matrixes

AP1	A	B	C	D	E	F	G	H	I	J	K	L
Manufacturing stations / Level of automation	Rollforming tailgate	Fitting cockpit location brackets	Rollforming doors	Cleaning window flange, Closing tailgate	Priming window flange, Opening bonnet	Applying cockpit glue	Cockpit fitting 1	Removing cable box, Remaining screw connections	Remaining screw connections	Cockpit fitting 2	Removing cable box, Remaining screw connections	Remaining screw connections
Level of automation (Golf A5 WOB)	automatic (1 robot)	automatic (2 facilities)	automatic (4 robots)	automatic (3 robots)	automatic (3 robots)	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)
Level of automation (Auto5000 WOB)	manual (handrollforming device)		manual (handrollforming device)	manual	manual	automatic (1 robot)	manual (manipulator with sensors and electrical screwdriver)			manual (manipulator and electrical screwdriver)		
Level of automation (Golf A5 SA)	manual (handrollforming device)	manual (electrical screwdriver and jigs)	manual (handrollforming device)	manual	manual	manual (manipulator without sensors, electrical screwdriver and 1 system)						

Assembly Part 1, generation and meaning of the matrix

AP2 Manufacturing stations / Level of automation	A	B	C	D	E	F	G	H
	Stamping Vehicle Identification Number (VIN) (3 times)	Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	Fitting gear shift	Closing bonnet	Lifting down	Fitting windscreen 1, Fitting rear glass 1	Fitting windscreen 2, Fitting rear glass 2	Fitting side glasses
Level of automation (Golf A5 WOB)	automatic (2 robots and 1 facility)	automatic (18 facilities, 1 robot and 1 lifter)	automatic (1 robot)	automatic (1 robot)	automatic (3 facilities and 1 lifter)	automatic (2 robots)	automatic (2 robots)	automatic (4 robots)
Level of automation (Auto5000 WOB)	manual (3 manipula-tors)	automatic (18 facilities, 1 robot and 1 lifter)	manual (accu screw-drive)	manual	automatic (3 facilities and 1 lifter)	manual (2 robots)		manual (1 robot)
Level of automation (Golf A5 SA)	manual (3 manipula-tors)	manual (3 facilities and 1 lifter)	manual (accu screw-driver)	manual		manual (2 robots)		manual (1 robot)

Assembly Part 2, generation and meaning of the matrix

AP3	A	B	C	D	E	F	G	H	I	J
Manufacturing stations / Level of automation	Opening bonnet	Putting in/Fitting the CW-trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels
Level of automation (Golf A5 WOB)	automatic (1 facility)	automatic (2 facilities)	automatic (1 robot and 0,5 manipulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)
Level of automation (Auto5000 WOB)	manual	manual (accu screw-driver)	manual (accu screwdriver)		manual (electrical screwdriver)	manual (accu screw-driver)	manual (manipulator with sensors)	manual (accu screw-driver)	manual (manipulator)	manual (2 supporters, accu screw-driver and 2 manipulator)
Level of automation (Golf A5 SA)	manual	manual (accu screw-driver)	manual (accu screwdriver)		manual (electrical screwdriver)	manual (accu screw-driver)	manual (manipulator without sensors)	manual (accu screw-driver)	manual	manual (electrical screwdriver)

Assembly Part 3, generation and meaning of the matrix

Appendix H

Determining of the optimal level of automation:

Matrixes of Assembly Parts, analyses of used quality values, determined results

Golf A5 Uitenhage, Assembly Part 1, Level of automation 1

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	**33500**	€/year			
Personnel costs rate master C_{P_M}	**15200**	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	**14400**	€/year			
Personnel costs rate depositor C_{P_D}	**14400**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Personnel costs

Station	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}
	$c_{P\_..j}=\frac{t_{M\_..j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$
Rollforming tailgate	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,56 €	0,0784 €	0,0008 €
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,25 €	0,0350 €	0,0008 €
Rollforming doors	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	1,30 €	0,1813 €	0,0008 €
Cleaning window flange, Closing tailgate	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	1,26 €	0,1764 €	0,0008 €
Priming window flange, Opening bonnet	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	1,61 €	0,2254 €	0,0008 €
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,53 €	0,0735 €	0,0008 €
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	2,24 €	0,3136 €	0,0008 €
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	2,24 €	0,3136 €	0,0008 €
Removing cable box, Remaining screw connections	2,325	0,29 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,036	0,02 €	0,25 €	0,0350 €	0,0023 €
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,65 €	0,0910 €	0,0008 €
Total:	2,325		0,14		1,143		6,732		0		0,153				
Total net costs per unit:		0,29 €		0,02 €		0,18 €		0,81 €		0,00 €		0,11 €	10,89 €	1,52 €	0,01 €
Total gross costs per unit (+5%):		0,30 €		0,02 €		0,19 €		0,85 €		0,00 €		0,12 €	11,43 €	1,60 €	0,01 €

Operating material / Material

Station	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		Total per station (gross)
	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	
Rollforming tailgate	396.000 €	1,12 €	10	0,033 €	0,161 €	0,5	0,002 €	2,11 €
Fitting cockpit location brackets	176.000 €	0,50 €	20	0,065 €	0,071 €	1,5	0,005 €	1,07 €
Rollforming doors	918.000 €	2,59 €	40	0,131 €	0,373 €	1	0,003 €	4,78 €
Cleaning window flange, Closing tailgate	891.000 €	2,52 €	30	0,098 €	0,362 €	1	0,003 €	4,62 €
Priming window flange, Opening bonnet	1.141.000 €	3,22 €	30	0,098 €	0,463 €	1	0,003 €	5,84 €
Applying cockpit glue	371.000 €	1,05 €	10	0,033 €	0,151 €	1,5	0,005 €	2,00 €
Cockpit fitting 1	1.586.000 €	4,48 €	60	0,196 €	0,644 €	4,5	0,015 €	8,14 €
Cockpit fitting 2	1.586.000 €	4,48 €	60	0,196 €	0,644 €	4,5	0,015 €	8,14 €
Removing cable box, Remaining screw connections	176.000 €	0,50 €	1	0,003 €	0,071 €	1	0,003 €	1,23 €
Remaining screw connections	461.000 €	1,30 €	10	0,033 €	0,187 €	1	0,003 €	2,43 €
Total gross costs per unit (+5%):		21,76 €		0,89 €	3,13 €		0,06 €	

Total costs per unit: 40,36 €

Golf A5 Uitenhage, Assembly Part 1, Level of automation 2

Parameters:

Cycle time t_C	4,550	min/unit	number of units n	50549	unit/year
Shift time t_{SH}	460	min/shift			
Number of shifts n_S	2	shifts/day			
Working days d_W	250	days/year			
Personnel costs rate IE C_{P_IE}	33500	€/year			
Personnel costs rate master C_{P_M}	15200	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	14400	€/year			
Personnel costs rate depositor C_{P_D}	14400	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_SA}	62	€/kW*year			
Energy costs rate C_{W_SA}	0,027	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,25 €	0,0350 €	0,0008 €	176.000 €	0,50 €	20	0,065 €	0,071 €	1,5	0,005 €	1,07 €
Cleaning window flange, Closing tailgate	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	1,26 €	0,1764 €	0,0008 €	891.000 €	2,52 €	30	0,098 €	0,362 €	1	0,003 €	4,62 €
Priming window flange, Opening bonnet	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	1,61 €	0,2254 €	0,0008 €	1.141.000 €	3,22 €	30	0,098 €	0,463 €	1	0,003 €	5,84 €
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,53 €	0,0735 €	0,0008 €	371.000 €	1,05 €	10	0,033 €	0,151 €	1,5	0,005 €	2,00 €
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	2,24 €	0,3136 €	0,0008 €	1.586.000 €	4,48 €	60	0,196 €	0,644 €	4,5	0,015 €	8,14 €
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	2,24 €	0,3136 €	0,0008 €	1.586.000 €	4,48 €	60	0,196 €	0,644 €	4,5	0,015 €	8,14 €
Removing cable box, Remaining screw connections	2,325	0,29 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,036	0,02 €	0,25 €	0,0350 €	0,0023 €	176.000 €	0,50 €	1	0,003 €	0,071 €	1	0,003 €	1,23 €
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,65 €	0,0910 €	0,0008 €	461.000 €	1,30 €	10	0,033 €	0,187 €	1	0,003 €	2,43 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	
Rollforming tailgate	1,07	0,13 €	0,28	0,04 €	0	0,00 €	0	0,00 €	0	0,00 €	0,020	0,01 €	0,05 €	0,0070 €	0,0013 €	34.000 €	0,10 €	1	0,003 €	0,013 €	0,5	0,002 €	0,37 €
Rollforming doors	2,4	0,30 €	0,28	0,04 €	0	0,00 €	0	0,00 €	0	0,00 €	0,039	0,02 €	0,10 €	0,0133 €	0,0025 €	68.000 €	0,19 €	1	0,003 €	0,026 €	1	0,003 €	0,72 €
Total:	5,795		0,7		0,889		5,236		0		0,186												
Total net costs per unit:		0,72 €		0,10 €		0,14 €		0,63 €		0,00 €		0,12 €	9,18 €	1,28 €	0,01 €								
Total gross costs per unit (+5%):		0,76 €		0,11 €		0,15 €		0,66 €		0,00 €		0,13 €	9,64 €	1,34 €	0,01 €		18,34 €		0,73 €	2,63 €		0,06 €	

Total costs per unit: 34,56 €

Golf A5 Uitenhage, Assembly Part 1, Level of automation 3

Parameters:

Cycle time t_C	4,550	min/unit	number of units n	50549	unit/year
Shift time t_{SH}	460	min/shift			
Number of shifts n_S	2	shifts/day			
Working days d_W	250	days/year			
Personnel costs rate IE C_{P_IE}	33500	€/year			
Personnel costs rate master C_{P_M}	15200	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	14400	€/year			
Personnel costs rate depositor C_{P_D}	14400	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_SA}	62	€/kW*year			
Energy costs rate C_{W_SA}	0,027	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,25 €	0,0350 €	0,0008 €	176.000 €	0,50 €	20	0,065 €	0,071 €	1,5	0,005 €	1,07 €
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,53 €	0,0735 €	0,0008 €	371.000 €	1,05 €	10	0,033 €	0,151 €	1,5	0,005 €	2,00 €
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	2,24 €	0,3136 €	0,0008 €	1.586.000 €	4,48 €	60	0,196 €	0,644 €	4,5	0,015 €	8,14 €
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	2,24 €	0,3136 €	0,0008 €	1.586.000 €	4,48 €	60	0,196 €	0,644 €	4,5	0,015 €	8,14 €
Removing cable box, Remaining screw connections	2,325	0,29 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,036	0,02 €	0,25 €	0,0350 €	0,0023 €	176.000 €	0,50 €	1	0,003 €	0,071 €	1	0,003 €	1,23 €
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,02 €	0,748	0,09 €	0	0,00 €	0,013	0,01 €	0,65 €	0,0910 €	0,0008 €	461.000 €	1,30 €	10	0,033 €	0,187 €	1	0,003 €	2,43 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	
Rollforming tailgate	1,07	0,13 €	0,28	0,04 €	0	0,00 €	0	0,00 €	0	0,00 €	0,020	0,01 €	0,05 €	0,0070 €	0,0013 €	34.000 €	0,10 €	1	0,003 €	0,013 €	0,5	0,002 €	0,37 €
Rollforming doors	2,4	0,30 €	0,28	0,04 €	0	0,00 €	0	0,00 €	0	0,00 €	0,039	0,02 €	0,10 €	0,0133 €	0,0025 €	68.000 €	0,19 €	1	0,003 €	0,026 €	1	0,003 €	0,72 €
Cleaning window flange, Closing tailgate	2,81	0,35 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,043	0,03 €	0,00 €	0,0000 €	0,0028 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,42 €
Priming window flange, Opening bonnet	2,81	0,35 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,043	0,03 €	0,00 €	0,0000 €	0,0028 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,42 €
Total:	11,415		0,98		0,635		3,74		0		0,246												
Total net costs per unit:		1,42 €		0,14 €		0,10 €		0,45 €		0,00 €		0,16 €	6,31 €	0,88 €	0,02 €								
Total gross costs per unit (+5%):		1,49 €		0,15 €		0,11 €		0,47 €		0,00 €		0,17 €	6,63 €	0,92 €	0,02 €		12,60 €		0,53 €	1,81 €		0,05 €	

Total costs per unit: 24,94 €

Golf A5 Uitenhage, Assembly Part 1, Level of automation 4

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	33500	€/year			
Personnel costs rate master C_{P_M}	15200	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	14400	€/year			
Personnel costs rate depositor C_{P_D}	14400	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	
Applying cockpit glue	0	0,00 €	0	0,00 €	**0,127**	0,02 €	**0,748**	0,09 €	0	0,00 €	0,013	0,01 €	0,53 €	0,0735 €	0,0008 €	**371.000 €**	1,05 €	**10**	0,033 €	0,151 €	**1,5**	0,005 €	2,00 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	
Rollforming tailgate	**1,07**	0,13 €	**0,28**	0,04 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,020	0,01 €	0,05 €	0,0070 €	0,0013 €	**34.000 €**	0,10 €	**1**	0,003 €	0,013 €	**0,5**	0,002 €	0,37 €
Fitting cockpit location brackets	**2,55**	0,32 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,039	0,02 €	0,25 €	0,0350 €	0,0025 €	**176.000 €**	0,50 €	**1**	0,003 €	0,066 €	**0,5**	0,002 €	1,25 €
Rollforming doors	**2,4**	0,30 €	**0,28**	0,04 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,039	0,02 €	0,10 €	0,0133 €	0,0025 €	**68.000 €**	0,19 €	**1**	0,003 €	0,026 €	**1**	0,003 €	0,72 €
Cleaning window flange, Closing tailgate	**2,81**	0,35 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,043	0,03 €	0,00 €	0,0000 €	0,0028 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,42 €
Priming window flange, Opening bonnet	**2,81**	0,35 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,043	0,03 €	0,00 €	0,0000 €	0,0028 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,42 €
Cockpit fitting 1	**3,906**	0,49 €	**0,41**	0,05 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,063	0,04 €	1,14 €	0,1596 €	0,0041 €	**805.500 €**	2,28 €	**65**	0,213 €	0,303 €	**5**	0,016 €	4,79 €
Cockpit fitting 2	**3,906**	0,49 €	**0,41**	0,05 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,063	0,04 €	1,14 €	0,1596 €	0,0041 €	**805.500 €**	2,28 €	**65**	0,213 €	0,303 €	**5**	0,016 €	4,79 €
Total:	19,452		1,8		0,127		0,748		0		0,323												
Total net costs per unit:		2,43 €		0,24 €		0,02 €		0,09 €		0,00 €		0,20 €	3,21 €	0,45 €	0,02 €								
Total gross costs per unit (+5%):		2,55 €		0,25 €		0,02 €		0,09 €		0,00 €		0,21 €	3,37 €	0,47 €	0,02 €		6,40 €		0,47 €	0,86 €		0,04 €	

Total costs per unit: 14,76 €

Golf A5 Uitenhage, Assembly Part 1, Level of automation 5

Parameters:

Cycle time t_C	4,550	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	460	min/shift			
Number of shifts n_S	2	shifts/day			
Working days d_W	250	days/year			
Personnel costs rate IE C_{P_IE}	33500	€/year			
Personnel costs rate master C_{P_M}	15200	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	14400	€/year			
Personnel costs rate depositor C_{P_D}	14400	€/year			
Period of depreciation **a**	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_SA}	62	€/kW*year			
Energy costs rate C_{W_SA}	0,027	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_w}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60min/h}$	
Rollforming tailgate	**1,07**	0,13 €	**0,28**	0,04 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,020	0,01 €	0,05 €	0,0070 €	0,0013 €	**34.000 €**	0,10 €	**1**	0,003 €	0,013 €	**0,5**	0,002 €	0,37 €
Fitting cockpit location brackets	**2,55**	0,32 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,039	0,02 €	0,25 €	0,0350 €	0,0025 €	**176.000 €**	0,50 €	**1**	0,003 €	0,066 €	**0,5**	0,002 €	1,25 €
Rollforming doors	**2,4**	0,30 €	**0,28**	0,04 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,039	0,02 €	0,10 €	0,0133 €	0,0025 €	**68.000 €**	0,19 €	**1**	0,003 €	0,026 €	**1**	0,003 €	0,72 €
Cleaning window flange, Closing tailgate	**2,81**	0,35 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,043	0,03 €	0,00 €	0,0000 €	0,0028 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,42 €
Priming window flange, Opening bonnet	**2,81**	0,35 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,043	0,03 €	0,00 €	0,0000 €	0,0028 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,42 €

Stations with parameters that are taken from Golf A5 SA:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_w}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_SA}}{n}+\frac{P_{Ej}\cdot C_{W\_SA}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_SA}}\cdot C_{EQ\_SA}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60min/h}$	
Cockpit fitting	**14,9**	1,87 €	**0,55**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,226	0,14 €	0,27 €	0,0378 €	0,0146 €	**192.000 €**	0,54 €	**11**	0,036 €	0,195 €	**3**	0,010 €	3,30 €

Total:	26,54		1,53		0		0		0		0,410											
Total net costs per unit:		3,32 €		0,21 €		0,00 €		0,00 €		0,00 €		0,25 €	0,67 €	0,09 €	0,03 €							
Total gross costs per unit (+5%):		3,49 €		0,22 €		0,00 €		0,00 €		0,00 €		0,26 €	0,70 €	0,09 €	0,03 €		1,33 €		0,05 €	0,30 €		0,02 €

Total costs per unit: 6,48 €

Golf A5 Uitenhage, Assembly Part 2, Level of automation 1

Parameters:

Cycle time t_C	4,550	min/unit	number of units n	50549	unit/year
Shift time t_{SH}	460	min/shift			
Number of shifts n_S	2	shifts/day			
Working days d_W	250	days/year			
Personnel costs rate IE C_{P_IE}	33500	€/year			
Personnel costs rate master C_{P_M}	15200	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	14400	€/year			
Personnel costs rate depositor C_{P_D}	14400	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_SA}	62	€/kW*year			
Energy costs rate C_{W_SA}	0,027	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Personnel costs

Station	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$
Stamping VIN	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0	0,00 €	0,014	0,01 €	1,30 €	0,1813 €	0,0009 €
Lifting up and fitting complete powertrain, Underbody work	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0	0,00 €	0,014	0,01 €	3,67 €	0,5138 €	0,0009 €
Fitting gear shift	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0	0,00 €	0,014	0,01 €	0,74 €	0,1036 €	0,0009 €
Closing bonnet	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0	0,00 €	0,014	0,01 €	0,06 €	0,0077 €	0,0009 €
Lifting down fitting unit	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0	0,00 €	0,014	0,01 €	0,82 €	0,1148 €	0,0009 €
Fitting rear glass/windscreen 1	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0,286	0,04 €	0,018	0,01 €	0,92 €	0,1281 €	0,0012 €
Fitting rear glass/windscreen 2	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0,286	0,04 €	0,018	0,01 €	0,92 €	0,1281 €	0,0012 €
Fitting side glasses	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0,572	0,07 €	0,023	0,01 €	0,92 €	0,1281 €	0,0015 €
Total:	0		0		2,857		4,894		1,143		0,129				
Total net costs per unit:		0,00 €		0,00 €		0,32 €		0,64 €		0,15 €		0,08 €	9,35 €	1,31 €	0,01 €
Total gross costs per unit (+5%):		0,00 €		0,00 €		0,34 €		0,67 €		0,16 €		0,08 €	9,82 €	1,38 €	0,01 €

Operating material / Material

Station	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		Total per station (gross)
	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60min/h}$	
Stamping VIN	915.000 €	2,59 €	15	0,049 €	0,372 €	0,5	0,002 €	4,71 €
Lifting up and fitting complete powertrain, Underbody work	2.597.000 €	7,34 €	30	0,098 €	1,054 €	3	0,010 €	13,03 €
Fitting gear shift	523.000 €	1,48 €	8	0,026 €	0,212 €	0,5	0,002 €	2,74 €
Closing bonnet	40.000 €	0,11 €	1	0,003 €	0,016 €	0,5	0,002 €	0,34 €
Lifting down fitting unit	580.000 €	1,64 €	2	0,007 €	0,235 €	0	0,000 €	3,00 €
Fitting rear glass/windscreen 1	647.000 €	1,83 €	15	0,049 €	0,263 €	1	0,003 €	3,43 €
Fitting rear glass/windscreen 2	647.000 €	1,83 €	15	0,049 €	0,263 €	1	0,003 €	3,43 €
Fitting side glasses	647.000 €	1,83 €	25	0,082 €	0,263 €	1	0,003 €	3,49 €
Total gross costs per unit (+5%):		18,65 €		0,36 €	2,68 €		0,03 €	

Total costs per unit: 34,17 €

Golf A5 Uitenhage, Assembly Part 2, Level of automation 2

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	**33500**	€/year			
Personnel costs rate master C_{P_M}	**15200**	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	**14400**	€/year			
Personnel costs rate depositor C_{P_D}	**14400**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j}=\frac{t_{M\_..j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	
Lifting up and fitting complete powertrain, Underbody work	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0**	0,00 €	0,014	0,01 €	3,67 €	0,5138 €	0,0009 €	**2.597.000 €**	7,34 €	**30**	0,098 €	1,054 €	**3**	0,010 €	13,03 €
Fitting gear shift	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0**	0,00 €	0,014	0,01 €	0,74 €	0,1036 €	0,0009 €	**523.000 €**	1,48 €	**8**	0,026 €	0,212 €	**0,5**	0,002 €	2,74 €
Closing bonnet	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0**	0,00 €	0,014	0,01 €	0,06 €	0,0077 €	0,0009 €	**40.000 €**	0,11 €	**1**	0,003 €	0,016 €	**0,5**	0,002 €	0,34 €
Lifting down fitting unit	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0**	0,00 €	0,014	0,01 €	0,82 €	0,1148 €	0,0009 €	**580.000 €**	1,64 €	**2**	0,007 €	0,235 €	**0**	0,000 €	3,00 €
Fitting rear glass/windscreen 1	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0,286**	0,04 €	0,018	0,01 €	0,92 €	0,1281 €	0,0012 €	**647.000 €**	1,83 €	**15**	0,049 €	0,263 €	**1**	0,003 €	3,43 €
Fitting rear glass/windscreen 2	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0,286**	0,04 €	0,018	0,01 €	0,92 €	0,1281 €	0,0012 €	**647.000 €**	1,83 €	**15**	0,049 €	0,263 €	**1**	0,003 €	3,43 €
Fitting side glasses	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0,572**	0,07 €	0,023	0,01 €	0,92 €	0,1281 €	0,0015 €	**647.000 €**	1,83 €	**25**	0,082 €	0,263 €	**1**	0,003 €	3,49 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j}=\frac{t_{M\_..j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	
Stamping VIN	**2,3**	0,29 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,036	0,02 €	0,90 €	0,1260 €	0,0023 €	**636.000 €**	1,80 €	**5**	0,016 €	0,239 €	**3**	0,010 €	3,49 €

	t_{M_DW}	c_{P_DW}	t_{M_QCC}	c_{P_QCC}	t_{M_RW}	c_{P_RW}	t_{M_OW}	c_{P_OW}	t_{M_D}	c_{P_D}	n_M	c_{P_M}	c_{P_MA}	c_{P_P}	c_{P_IE}	C_{INV}	c_{INV}	P_E	c_E	c_{EQ}	P_{OS}	c_{OS}
Total:	2,300		0,140		2,500		4,282		1,143		0,151											
Total net costs per unit:		0,29 €		0,02 €		0,28 €		0,56 €		0,15 €		0,09 €	8,95 €	1,25 €	0,01 €							
Total gross costs per unit (+5%):		0,30 €		0,02 €		0,29 €		0,59 €		0,16 €		0,09 €	9,40 €	1,31 €	0,01 €		17,86 €		0,33 €	2,55 €		0,03 €

Total costs per unit: 32,95 €

Golf A5 Uitenhage, Assembly Part 2, Level of automation 3

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	**33500**	€/year			
Personnel costs rate master C_{P_M}	**15200**	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	**14400**	€/year			
Personnel costs rate depositor C_{P_D}	**14400**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_M \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	
Lifting up and fitting complete powertrain, Underbody work	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0**	0,00 €	0,014	0,01 €	3,67 €	0,5138 €	0,0009 €	**2.597.000 €**	7,34 €	**30**	0,098 €	1,054 €	**3**	0,010 €	13,03 €
Lifting down fitting unit	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0**	0,00 €	0,014	0,01 €	0,82 €	0,1148 €	0,0009 €	**580.000 €**	1,64 €	**2**	0,007 €	0,235 €	**0**	0,000 €	3,00 €
Fitting rear glass/windscreen 1	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0,286**	0,04 €	0,018	0,01 €	0,92 €	0,1281 €	0,0012 €	**647.000 €**	1,83 €	**15**	0,049 €	0,263 €	**1**	0,003 €	3,43 €
Fitting rear glass/windscreen 2	**0**	0,00 €	**0**	0,00 €	**0,357**	0,04 €	**0,612**	0,08 €	**0,286**	0,04 €	0,018	0,01 €	0,92 €	0,1281 €	0,0012 €	**647.000 €**	1,83 €	**15**	0,049 €	0,263 €	**1**	0,003 €	3,43 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_M \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	
Stamping VIN	**2,3**	0,29 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,036	0,02 €	0,90 €	0,1260 €	0,0023 €	**636.000 €**	1,80 €	**5**	0,016 €	0,239 €	**3**	0,010 €	3,49 €
Fitting gear shift	**1,2**	0,15 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,020	0,01 €	0,02 €	0,0021 €	0,0013 €	**11.000 €**	0,03 €	**1**	0,003 €	0,004 €	**0,5**	0,002 €	0,25 €
Closing bonnet	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,00 €
Fitting side glasses	**1,252**	0,16 €	**0,55**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,026	0,02 €	0,42 €	0,0588 €	0,0017 €	**297.000 €**	0,84 €	**10**	0,033 €	0,112 €	**1**	0,003 €	1,76 €
Total:	4,752		0,830		1,429		2,447		0,572		0,146												
Total net costs per unit:		0,60 €		0,11 €		0,16 €		0,32 €		0,08 €		0,09 €	7,67 €	1,07 €	0,01 €								
Total gross costs per unit (+5%):		0,63 €		0,12 €		0,17 €		0,34 €		0,08 €		0,09 €	8,05 €	1,12 €	0,01 €		15,31 €		0,26 €	2,17 €		0,03 €	

Total costs per unit: 28,39 €

Golf A5 Uitenhage, Assembly Part 2, Level of automation 4

Parameters:

Cycle time t_C	4,550	min/unit	number of units n	50549	unit/year
Shift time t_{SH}	460	min/shift			
Number of shifts n_S	2	shifts/day			
Working days d_W	250	days/year			
Personnel costs rate IE C_{P_IE}	33500	€/year			
Personnel costs rate master C_{P_M}	15200	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	14400	€/year			
Personnel costs rate depositor C_{P_D}	14400	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_SA}	62	€/kW*year			
Energy costs rate C_{W_SA}	0,027	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	
Lifting up and fitting complete powertrain, Underbody work	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0	0,00 €	0,014	0,01 €	3,67 €	0,5138 €	0,0009 €	2.597.000 €	7,34 €	30	0,098 €	1,054 €	3	0,010 €	13,03 €
Lifting down fitting unit	0	0,00 €	0	0,00 €	0,357	0,04 €	0,612	0,08 €	0	0,00 €	0,014	0,01 €	0,82 €	0,1148 €	0,0009 €	580.000 €	1,64 €	2	0,007 €	0,235 €	0	0,000 €	3,00 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	
Stamping VIN	2,3	0,29 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,036	0,02 €	0,90 €	0,1260 €	0,0023 €	636.000 €	1,80 €	5	0,016 €	0,239 €	3	0,010 €	3,49 €
Fitting gear shift	1,2	0,15 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,020	0,01 €	0,02 €	0,0021 €	0,0013 €	11.000 €	0,03 €	1	0,003 €	0,004 €	0,5	0,002 €	0,25 €
Closing bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Fitting rear glass/windscreen 1	3,2	0,40 €	0,55	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,055	0,03 €	0,56 €	0,0777 €	0,0036 €	394.000 €	1,11 €	20	0,065 €	0,148 €	1	0,003 €	2,52 €
Fitting side glasses	1,252	0,16 €	0,55	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,026	0,02 €	0,42 €	0,0588 €	0,0017 €	297.000 €	0,84 €	10	0,033 €	0,112 €	1	0,003 €	1,76 €
Total:	7,952		1,380		0,714		1,224		0,000		0,165												
Total net costs per unit:		1,00 €		0,18 €		0,08 €		0,16 €		0,00 €		0,10 €	6,39 €	0,89 €	0,01 €								
Total gross costs per unit (+5%):		1,05 €		0,19 €		0,08 €		0,17 €		0,00 €		0,11 €	6,71 €	0,93 €	0,01 €		12,76 €		0,22 €	1,79 €		0,03 €	

Total costs per unit: 24,05 €

Golf A5 Uitenhage, Assembly Part 2, Level of automation 5

Parameters:

Cycle time t_C	4,550	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	460	min/shift			
Number of shifts n_S	2	shifts/day			
Working days d_W	250	days/year			
Personnel costs rate IE C_{P_IE}	33500	€/year			
Personnel costs rate master C_{P_M}	15200	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	14400	€/year			
Personnel costs rate depositor C_{P_D}	14400	€/year			
Period of depreciation **a**	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_SA}	62	€/kW*year			
Energy costs rate C_{W_SA}	0,027	€/kWh			

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
			$c_{P\_..j}=\frac{t_{M\_..j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$							$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$	$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW}}{n}+\frac{P_{Ej}\cdot C_{W}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV}}\cdot C_{EQ}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW}}{n}+\frac{P_{OSj}\cdot C_{W}\cdot t_C}{60min/h}$	
Stations with parameters that are taken from Auto5000 Wolfsburg:																							
Stamping VIN	**2,3**	0,29 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,036	0,02 €	0,90 €	0,1260 €	0,0023 €	**636.000 €**	1,80 €	**5**	0,016 €	0,239 €	**3**	0,010 €	3,49 €
Fitting gear shift	**1,2**	0,15 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,020	0,01 €	0,02 €	0,0021 €	0,0013 €	**11.000 €**	0,03 €	**1**	0,003 €	0,004 €	**0,5**	0,002 €	0,25 €
Closing bonnet	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,00 €
Fitting rear glass/windscreen 1	**3,2**	0,40 €	**0,55**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,055	0,03 €	0,56 €	0,0777 €	0,0036 €	**394.000 €**	1,11 €	**20**	0,065 €	0,148 €	**1**	0,003 €	2,52 €
Fitting side glasses	**1,252**	0,16 €	**0,55**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,026	0,02 €	0,42 €	0,0588 €	0,0017 €	**297.000 €**	0,84 €	**10**	0,033 €	0,112 €	**1**	0,003 €	1,76 €
Stations with parameters that are taken from Golf A5 SA:																							
																				$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_SA}}\cdot C_{EQ\_SA}$			
Lifting up and fitting complete powertrain, Underbody work	**45,34**	5,68 €	**0,83**	0,10 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,676	0,41 €	0,86 €	0,1197 €	0,0437 €	**605.000 €**	1,71 €	**10**	0,033 €	0,615 €	**3**	0,010 €	9,94 €
Total:	53,292		2,210		0,000		0,000		0,000		0,813												
Total net costs per unit:		6,68 €		0,28 €		0,00 €		0,00 €		0,00 €		0,49 €	2,76 €	0,38 €	0,05 €								
Total gross costs per unit (+5%):		7,01 €		0,29 €		0,00 €		0,00 €		0,00 €		0,51 €	2,90 €	0,40 €	0,06 €		5,49 €		0,15 €	1,12 €		0,03 €	

Total costs per unit: 17,96 €

Golf A5 Uitenhage, Assembly Part 3, Level of automation 1

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	**33500**	€/year			
Personnel costs rate master C_{P_M}	**15200**	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	**14400**	€/year			
Personnel costs rate depositor C_{P_D}	**14400**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_\ldots j} = \frac{t_{M\_\ldots j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	
Opening bonnet	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	0,03 €	0,0035 €	0,0005 €	**17.600 €**	0,05 €	**8**	0,026 €	0,007 €	**0,5**	0,002 €	0,18 €
Putting in/Fitting CW trim panel	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0,572**	0,07 €	0,016	0,01 €	1,04 €	0,1449 €	0,0010 €	**731.000 €**	2,07 €	**10**	0,033 €	0,297 €	**1**	0,003 €	3,80 €
Putting in battery	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0,572**	0,07 €	0,016	0,01 €	0,61 €	0,0854 €	0,0010 €	**431.000 €**	1,22 €	**10**	0,033 €	0,175 €	**0,5**	0,002 €	2,31 €
Fitting battery	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	0,30 €	0,0413 €	0,0005 €	**210.000 €**	0,59 €	**8**	0,026 €	0,085 €	**1**	0,003 €	1,13 €
Fitting cross member	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	0,53 €	0,0735 €	0,0005 €	**373.000 €**	1,05 €	**15**	0,049 €	0,151 €	**1**	0,003 €	1,95 €
Fitting rear bumper	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	1,04 €	0,1449 €	0,0005 €	**733.000 €**	2,07 €	**10**	0,033 €	0,298 €	**0,5**	0,002 €	3,71 €
Fitting frontend	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	1,10 €	0,1540 €	0,0005 €	**777.000 €**	2,20 €	**30**	0,098 €	0,315 €	**1**	0,003 €	4,00 €
Placing spare wheel in boot	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	0,34 €	0,0476 €	0,0005 €	**242.000 €**	0,68 €	**10**	0,033 €	0,098 €	**0,5**	0,002 €	1,28 €
Premounting/Fitting wheels	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	1,68 €	0,2352 €	0,0005 €	**1.190.000 €**	3,36 €	**30**	0,098 €	0,483 €	**2**	0,007 €	6,02 €
Total:	0		0		2,286		2,286		1,143		0,081												
Total net costs per unit:		0,00 €		0,00 €		0,27 €		0,27 €		0,14 €		0,02 €	6,67 €	0,93 €	0,01 €								
Total gross costs per unit (+5%):		0,00 €		0,00 €		0,28 €		0,28 €		0,15 €		0,02 €	7,00 €	0,98 €	0,01 €		13,29 €		0,43 €	1,91 €		0,03 €	

Total costs per unit: 24,38 €

Golf A5 Uitenhage, Assembly Part 3, Level of automation 2

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	**33500**	€/year			
Personnel costs rate master C_{P_M}	**15200**	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	**14400**	€/year			
Personnel costs rate depositor C_{P_D}	**14400**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	
Putting in battery	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0,572**	0,07 €	0,016	0,01 €	0,61 €	0,0854 €	0,0010 €	**431.000 €**	1,22 €	**10**	0,033 €	0,175 €	**0,5**	0,002 €	2,31 €
Fitting battery	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	0,30 €	0,0413 €	0,0005 €	**210.000 €**	0,59 €	**8**	0,026 €	0,085 €	**1**	0,003 €	1,13 €
Fitting cross member	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	0,53 €	0,0735 €	0,0005 €	**373.000 €**	1,05 €	**15**	0,049 €	0,151 €	**1**	0,003 €	1,95 €
Fitting rear bumper	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	1,04 €	0,1449 €	0,0005 €	**733.000 €**	2,07 €	**10**	0,033 €	0,298 €	**0,5**	0,002 €	3,71 €
Fitting frontend	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	1,10 €	0,1540 €	0,0005 €	**777.000 €**	2,20 €	**30**	0,098 €	0,315 €	**1**	0,003 €	4,00 €
Placing spare wheel in boot	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	0,34 €	0,0476 €	0,0005 €	**242.000 €**	0,68 €	**10**	0,033 €	0,098 €	**0,5**	0,002 €	1,28 €
Premounting/Fitting wheels	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	1,68 €	0,2352 €	0,0005 €	**1.190.000 €**	3,36 €	**30**	0,098 €	0,483 €	**2**	0,007 €	6,02 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	
Opening bonnet	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,00 €
Putting in/Fitting CW trim panel	**2,29**	0,29 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,036	0,02 €	0,02 €	0,0021 €	0,0023 €	**11.000 €**	0,03 €	**1**	0,003 €	0,004 €	**0,5**	0,002 €	0,41 €

	t_{M_DW}	c_{P_DW}	t_{M_QCC}	c_{P_QCC}	t_{M_RW}	c_{P_RW}	t_{M_OW}	c_{P_OW}	t_{M_D}	c_{P_D}	n_M	c_{P_M}	c_{P_MA}	c_{P_P}	c_{P_IE}	c_{INV}	c_E	c_{EQ}	c_{OS}
Total:	2,290		0,140		1,778		1,778		0,572		0,094								
Total net costs per unit:		0,29 €		0,02 €		0,21 €		0,21 €		0,07 €		0,03 €	5,62 €	0,78 €	0,01 €				
Total gross costs per unit (+5%):		0,30 €		0,02 €		0,22 €		0,22 €		0,07 €		0,03 €	5,90 €	0,82 €	0,01 €	11,20 €	0,37 €	1,61 €	0,02 €

Total costs per unit: 20,81 €

Golf A5 Uitenhage, Assembly Part 3, Level of automation 3

Parameters:

Cycle time t_C	4,550	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	460	min/shift			
Number of shifts n_S	2	shifts/day			
Working days d_W	250	days/year			
Personnel costs rate IE C_{P_IE}	33500	€/year			
Personnel costs rate master C_{P_M}	15200	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	14400	€/year			
Personnel costs rate depositor C_{P_D}	14400	€/year			
Period of depreciation **a**	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_SA}	62	€/kW*year			
Energy costs rate C_{W_SA}	0,027	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var}) t_{M_DWj}	c_{P_DWj}	QCC-workers (c_{var}) t_{M_QCCj}	c_{P_QCCj}	Reworker (c_{var}) t_{M_RWj}	c_{P_RWj}	Other workers (c_{var}) t_{M_OWj}	c_{P_OWj}	Depositor (c_{var}) t_{M_Dj}	c_{P_Dj}	Master (c_{var}) n_{Mj}	c_{P_Mj}	Maintenance & technical service (c_{fix}) c_{P_MAj}	Planning (c_{fix}) c_{P_Pj}	Industrial engineering (c_{fix}) c_{P_IEj}	Operating material: Capital investment (c_{fix}) C_{INVj}	c_{INVj}	Energy (c_{fix}) P_{Ej}	c_{Ej}	Equipment (c_{fix}) c_{EQj}	Material: Operating supplies (c_{fix}) P_{OSj}	c_{OSj}	Total per station (gross)
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60min/h}$	
Putting in battery	0	0,00 €	0	0,00 €	0,254	0,03 €	0,254	0,03 €	0,572	0,07 €	0,016	0,01 €	0,61 €	0,0854 €	0,0010 €	431.000 €	1,22 €	10	0,033 €	0,175 €	10	0,033 €	2,34 €
Fitting battery	0	0,00 €	0	0,00 €	0,254	0,03 €	0,254	0,03 €	0	0,00 €	0,007	0,00 €	0,30 €	0,0413 €	0,0005 €	210.000 €	0,59 €	8	0,026 €	0,085 €	8	0,026 €	1,15 €
Fitting frontend	0	0,00 €	0	0,00 €	0,254	0,03 €	0,254	0,03 €	0	0,00 €	0,007	0,00 €	1,10 €	0,1540 €	0,0005 €	777.000 €	2,20 €	30	0,098 €	0,315 €	30	0,098 €	4,09 €
Placing spare wheel in boot	0	0,00 €	0	0,00 €	0,254	0,03 €	0,254	0,03 €	0	0,00 €	0,007	0,00 €	0,34 €	0,0476 €	0,0005 €	242.000 €	0,68 €	10	0,033 €	0,098 €	10	0,033 €	1,31 €
Premounting/Fitting wheels	0	0,00 €	0	0,00 €	0,254	0,03 €	0,254	0,03 €	0	0,00 €	0,007	0,00 €	1,68 €	0,2352 €	0,0005 €	1.190.000 €	3,36 €	30	0,098 €	0,483 €	30	0,098 €	6,11 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var}) t_{M_DWj}	c_{P_DWj}	QCC-workers (c_{var}) t_{M_QCCj}	c_{P_QCCj}	Reworker (c_{var}) t_{M_RWj}	c_{P_RWj}	Other workers (c_{var}) t_{M_OWj}	c_{P_OWj}	Depositor (c_{var}) t_{M_Dj}	c_{P_Dj}	Master (c_{var}) n_{Mj}	c_{P_Mj}	Maintenance & technical service (c_{fix}) c_{P_MAj}	Planning (c_{fix}) c_{P_Pj}	Industrial engineering (c_{fix}) c_{P_IEj}	Operating material: Capital investment (c_{fix}) C_{INVj}	c_{INVj}	Energy (c_{fix}) P_{Ej}	c_{Ej}	Equipment (c_{fix}) c_{EQj}	Material: Operating supplies (c_{fix}) P_{OSj}	c_{OSj}	Total per station (gross)
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	2,29	0,29 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,036	0,02 €	0,02 €	0,0021 €	0,0023 €	11.000 €	0,03 €	1	0,003 €	0,004 €	1	0,003 €	0,41 €
Fitting cross member	1,14	0,14 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,019	0,01 €	0,05 €	0,0070 €	0,0012 €	35.000 €	0,10 €	1	0,003 €	0,013 €	1	0,003 €	0,36 €
Fitting rear bumper	1,14	0,14 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,019	0,01 €	0,02 €	0,0021 €	0,0012 €	11.000 €	0,03 €	1	0,003 €	0,004 €	1	0,003 €	0,24 €
Total:	4,570		0,420		1,270		1,270		0,572		0,118												
Total net costs per unit:		0,57 €		0,06 €		0,15 €		0,15 €		0,07 €		0,05 €	4,12 €	0,57 €	0,01 €								
Total gross costs per unit (+5%):		0,60 €		0,06 €		0,16 €		0,16 €		0,07 €		0,05 €	4,33 €	0,60 €	0,01 €		8,21 €		0,30 €	1,18 €		0,30 €	

Total costs per unit: 16,01 €

Golf A5 Uitenhage, Assembly Part 3, Level of automation 4

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	**33500**	€/year			
Personnel costs rate master C_{P_M}	**15200**	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	**14400**	€/year			
Personnel costs rate depositor C_{P_D}	**14400**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	
Fitting frontend	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	1,10 €	0,1540 €	0,0005 €	**777.000 €**	2,20 €	**30**	0,098 €	0,315 €	**1**	0,003 €	4,00 €
Placing spare wheel in boot	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	0,34 €	0,0476 €	0,0005 €	**242.000 €**	0,68 €	**10**	0,033 €	0,098 €	**0,5**	0,002 €	1,28 €
Premounting/Fitting wheels	**0**	0,00 €	**0**	0,00 €	**0,254**	0,03 €	**0,254**	0,03 €	**0**	0,00 €	0,007	0,00 €	1,68 €	0,2352 €	0,0005 €	**1.190.000 €**	3,36 €	**30**	0,098 €	0,483 €	**2**	0,007 €	6,02 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_SA}}{n}+\frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	
Opening bonnet	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,00 €
Putting in/Fitting CW trim panel	**2,29**	0,29 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,036	0,02 €	0,02 €	0,0021 €	0,0023 €	**11.000 €**	0,03 €	**1**	0,003 €	0,004 €	**0,5**	0,002 €	0,41 €
Putting in/Fitting battery	**1,14**	0,14 €	**0,28**	0,04 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,021	0,01 €	0,13 €	0,0182 €	0,0013 €	**90.700 €**	0,26 €	**5**	0,016 €	0,034 €	**1,5**	0,005 €	0,67 €
Fitting cross member	**1,14**	0,14 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,019	0,01 €	0,05 €	0,0070 €	0,0012 €	**35.000 €**	0,10 €	**1**	0,003 €	0,013 €	**0,5**	0,002 €	0,36 €
Fitting rear bumper	**1,14**	0,14 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,019	0,01 €	0,02 €	0,0021 €	0,0012 €	**11.000 €**	0,03 €	**1**	0,003 €	0,004 €	**0,5**	0,002 €	0,24 €

Total:	5,710		0,700		0,763		0,763		0,000		0,116											
Total net costs per unit:		0,71 €		0,10 €		0,09 €		0,09 €		0,00 €		0,05 €	3,34 €	0,47 €	0,01 €							
Total gross costs per unit (+5%):		0,75 €		0,11 €		0,09 €		0,09 €		0,00 €		0,05 €	3,51 €	0,49 €	0,01 €		6,66 €		0,25 €	0,95 €		0,02 €

Total costs per unit: 12,98 €

Golf A5 Uitenhage, Assembly Part 3, Level of automation 5

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	**33500**	€/year			
Personnel costs rate master C_{P_M}	**15200**	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	**14400**	€/year			
Personnel costs rate depositor C_{P_D}	**14400**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	
Fitting frontend	0	0,00 €	0	0,00 €	0,254	0,03 €	0,254	0,03 €	0	0,00 €	0,007	0,00 €	1,10 €	0,1540 €	0,0005 €	777.000 €	2,20 €	30	0,098 €	0,315 €	1	0,003 €	4,00 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	2,29	0,29 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,036	0,02 €	0,02 €	0,0021 €	0,0023 €	11.000 €	0,03 €	1	0,003 €	0,004 €	0,5	0,002 €	0,41 €
Putting in/Fitting battery	1,14	0,14 €	0,28	0,04 €	0	0,00 €	0	0,00 €	0	0,00 €	0,021	0,01 €	0,13 €	0,0182 €	0,0013 €	90.700 €	0,26 €	5	0,016 €	0,034 €	1,5	0,005 €	0,67 €
Fitting cross member	1,14	0,14 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,019	0,01 €	0,05 €	0,0070 €	0,0012 €	35.000 €	0,10 €	1	0,003 €	0,013 €	0,5	0,002 €	0,36 €
Fitting rear bumper	1,14	0,14 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,019	0,01 €	0,02 €	0,0021 €	0,0012 €	11.000 €	0,03 €	1	0,003 €	0,004 €	0,5	0,002 €	0,24 €
Placing spare wheel in boot	0,728	0,09 €	0,14	0,02 €	0	0,00 €	0	0,00 €	0	0,00 €	0,013	0,01 €	0,10 €	0,0140 €	0,0008 €	70.000 €	0,20 €	5	0,016 €	0,026 €	0,5	0,002 €	0,49 €
Premounting/Fitting wheels	3,935	0,49 €	0,97	0,12 €	0	0,00 €	0	0,00 €	0	0,00 €	0,072	0,04 €	1,44 €	0,2016 €	0,0046 €	1.020.000 €	2,88 €	15	0,049 €	0,384 €	1,5	0,005 €	5,73 €
Total:	10,373		1,810		0,254		0,254		0,000		0,187												
Total net costs per unit:		1,29 €		0,24 €		0,03 €		0,03 €		0,00 €		0,10 €	2,86 €	0,40 €	0,01 €								
Total gross costs per unit (+5%):		1,35 €		0,25 €		0,03 €		0,03 €		0,00 €		0,11 €	3,00 €	0,42 €	0,01 €		5,70 €		0,19 €	0,78 €		0,02 €	

Total costs per unit: 11,90 €

Golf A5 Uitenhage, Assembly Part 3, Level of automation 6

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	**33500**	€/year			
Personnel costs rate master C_{P_M}	**15200**	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	**14400**	€/year			
Personnel costs rate depositor C_{P_D}	**14400**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWi}	c_{P_DWi}	t_{M_QCCi}	c_{P_QCCi}	t_{M_RWi}	c_{P_RWi}	t_{M_OWi}	c_{P_OWi}	t_{M_Di}	c_{P_Di}	n_{Mi}	c_{P_Mi}	c_{P_MAi}	c_{P_Pi}	c_{P_IEi}	C_{INVi}	c_{INVi}	P_{Ei}	c_{Ei}	c_{EQi}	P_{OSi}	c_{OSi}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mi} = n_{Mi} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ei} = \frac{P_{Ei} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ei} \cdot C_{W\_Auto5000} \cdot t_C}{60 min/h}$	$c_{EQi} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSi} = \frac{P_{OSi} \cdot C_{POW\_SA}}{n} + \frac{P_{OSi} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	
Opening bonnet	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,00 €
Putting in/Fitting CW trim panel	**2,29**	0,29 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,036	0,02 €	0,02 €	0,0021 €	0,0023 €	**11.000 €**	0,03 €	**1**	0,003 €	0,004 €	**0,5**	0,002 €	0,41 €
Putting in/Fitting battery	**1,14**	0,14 €	**0,28**	0,04 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,021	0,01 €	0,13 €	0,0182 €	0,0013 €	**90.700 €**	0,26 €	**5**	0,016 €	0,034 €	**1,5**	0,005 €	0,67 €
Fitting cross member	**1,14**	0,14 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,019	0,01 €	0,05 €	0,0070 €	0,0012 €	**35.000 €**	0,10 €	**1**	0,003 €	0,013 €	**0,5**	0,002 €	0,36 €
Fitting rear bumper	**1,14**	0,14 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,019	0,01 €	0,02 €	0,0021 €	0,0012 €	**11.000 €**	0,03 €	**1**	0,003 €	0,004 €	**0,5**	0,002 €	0,24 €
Fitting frontend	**6,86**	0,86 €	**0,56**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,109	0,07 €	1,47 €	0,2058 €	0,0070 €	**1.040.000 €**	2,94 €	**60**	0,196 €	0,392 €	**1,5**	0,005 €	6,35 €
Placing spare wheel in boot	**0,728**	0,09 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,013	0,01 €	0,10 €	0,0140 €	0,0008 €	**70.000 €**	0,20 €	**5**	0,016 €	0,026 €	**0,5**	0,002 €	0,49 €
Premounting/Fitting wheels	**3,935**	0,49 €	**0,97**	0,12 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,072	0,04 €	1,44 €	0,2016 €	0,0046 €	**1.020.000 €**	2,88 €	**15**	0,049 €	0,384 €	**1,5**	0,005 €	5,73 €
Total:	17,233		2,370		0,000		0,000		0,000		0,289												
Total net costs per unit:		2,15 €		0,31 €		0,00 €		0,00 €		0,00 €		0,17 €	3,23 €	0,45 €	0,02 €								
Total gross costs per unit (+5%):		2,26 €		0,33 €		0,00 €		0,00 €		0,00 €		0,18 €	3,39 €	0,47 €	0,02 €		6,44 €		0,29 €	0,86 €		0,02 €	

Total costs per unit: 14,25 €

Golf A5 Uitenhage, Assembly Part 3, Level of automation 7

Parameters:

Cycle time t_C	**4,550**	min/unit	number of units **n**	50549	unit/year
Shift time t_{SH}	**460**	min/shift			
Number of shifts n_S	**2**	shifts/day			
Working days d_W	**250**	days/year			
Personnel costs rate IE C_{P_IE}	**33500**	€/year			
Personnel costs rate master C_{P_M}	**15200**	€/year			
Personnel costs rate worker (operator, QCC) C_{P_W}	**14400**	€/year			
Personnel costs rate depositor C_{P_D}	**14400**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate C_{POW_SA}	**62**	€/kW*year			
Energy costs rate C_{W_SA}	**0,027**	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60min/h}$	
Opening bonnet	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,00 €
Putting in/Fitting CW trim panel	**2,29**	0,29 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,036	0,02 €	0,02 €	0,0021 €	0,0023 €	**11.000 €**	0,03 €	**1**	0,003 €	0,004 €	**0,5**	0,002 €	0,41 €
Fitting cross member	**1,14**	0,14 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,019	0,01 €	0,05 €	0,0070 €	0,0012 €	**35.000 €**	0,10 €	**1**	0,003 €	0,013 €	**0,5**	0,002 €	0,36 €
Fitting rear bumper	**1,14**	0,14 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,019	0,01 €	0,02 €	0,0021 €	0,0012 €	**11.000 €**	0,03 €	**1**	0,003 €	0,004 €	**0,5**	0,002 €	0,24 €

Stations with parameters that are taken from Golf A5 SA:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_SA}}{n} + \frac{P_{Ej} \cdot C_{W\_SA} \cdot t_C}{60min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_SA}} \cdot C_{EQ\_SA}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_SA}}{n} + \frac{P_{OSj} \cdot C_{W\_SA} \cdot t_C}{60min/h}$	
Putting in/Fitting battery	**1,38**	0,17 €	**0,28**	0,04 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,024	0,01 €	0,03 €	0,0042 €	0,0016 €	**20.000 €**	0,06 €	**1**	0,003 €	0,020 €	**0,5**	0,002 €	0,35 €
Fitting frontend	**8,6**	1,08 €	**0,56**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,134	0,08 €	0,32 €	0,0448 €	0,0087 €	**225.000 €**	0,64 €	**10**	0,033 €	0,229 €	**1**	0,003 €	2,59 €
Placing spare wheel in boot	**0,68**	0,09 €	**0,14**	0,02 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,012	0,01 €	0,00 €	0,0000 €	0,0008 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,13 €
Premounting/Fitting wheels	**6,64**	0,83 €	**0,97**	0,12 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,112	0,07 €	0,78 €	0,1085 €	0,0072 €	**550.000 €**	1,55 €	**5**	0,016 €	0,559 €	**1**	0,003 €	4,14 €
Total:	21,870		2,370		0,000		0,000		0,000		0,356												
Total net costs per unit:		2,74 €		0,31 €		0,00 €		0,00 €		0,00 €		0,21 €	1,22 €	0,17 €	0,02 €								
Total gross costs per unit (+5%):		2,88 €		0,33 €		0,00 €		0,00 €		0,00 €		0,22 €	1,28 €	0,18 €	0,02 €		2,41 €		0,06 €	0,83 €		0,01 €	

Total costs per unit: 8,22 €

Appendix G

Tables Golf A5 Uitenhage:

Calculation of total costs per unit

for each level of automation

Auto5000 GmbH, Assembly Part 1, Level of automation 1

Parameters:

Cycle time t_C	1,380	min/unit	number of units n	205565	unit/year
Shift time t_{SH}	394	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	240	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	56000	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	45000	€/year			
Personnel costs rate depositor C_{P_D}	45000	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate $C_{POW\_Auto5000}$	46	€/kW*year			
Energy costs rate $C_{W\_Auto5000}$	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	$t_{M\ DWj}$	$c_{P\ DWj}$	$t_{M\ QCCj}$	$c_{P\ QCCj}$	$t_{M\ RWj}$	$c_{P\ RWj}$	$t_{M\ OWj}$	$c_{P\ OWj}$	$t_{M\ Dj}$	$c_{P\ Dj}$	n_{Mj}	$c_{P\ Mj}$	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_...}}{n}+\frac{P_{OSj}\cdot C_{W\_...}\cdot t_C}{60min/h}$	
Rollforming tailgate	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,14 €	0,0196 €	0,0005 €	396.000 €	0,28 €	10	0,018 €	0,040 €	0,5	0,001 €	0,97 €
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,06 €	0,0084 €	0,0005 €	176.000 €	0,12 €	20	0,037 €	0,018 €	1,5	0,003 €	0,72 €
Rollforming doors	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,32 €	0,0448 €	0,0005 €	918.000 €	0,64 €	40	0,073 €	0,092 €	1	0,002 €	1,65 €
Cleaning window flange, Closing tailgate	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,31 €	0,0434 €	0,0005 €	891.000 €	0,62 €	30	0,055 €	0,089 €	1	0,002 €	1,60 €
Priming window flange, Opening bonnet	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,40 €	0,0553 €	0,0005 €	1.141.000 €	0,79 €	30	0,055 €	0,114 €	1	0,002 €	1,90 €
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,13 €	0,0182 €	0,0005 €	371.000 €	0,26 €	10	0,018 €	0,037 €	1,5	0,003 €	0,94 €
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,55 €	0,0770 €	0,0005 €	1.586.000 €	1,10 €	60	0,110 €	0,158 €	4,5	0,008 €	2,50 €
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,55 €	0,0770 €	0,0005 €	1.586.000 €	1,10 €	60	0,110 €	0,158 €	4,5	0,008 €	2,50 €
Removing cable box, Remaining screw connections	2,325	1,11 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,119	0,10 €	0,06 €	0,0084 €	0,0014 €	176.000 €	0,12 €	1	0,002 €	0,018 €	1	0,002 €	1,55 €
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,16 €	0,0224 €	0,0005 €	461.000 €	0,32 €	10	0,018 €	0,046 €	1	0,002 €	1,04 €
Total:	2,325		0,14		1,143		6,732		0		0,497												
Total net costs per unit:		1,11 €		0,07 €		0,54 €		3,24 €		0,00 €		0,37 €	2,68 €	0,37 €	0,01 €								
Total gross costs per unit (+4%):		1,15 €		0,07 €		0,56 €		3,37 €		0,00 €		0,38 €	2,79 €	0,38 €	0,01 €		5,35 €		0,50 €	0,77 €		0,03 €	

Total costs per unit: 15,37 €

Auto5000 GmbH, Assembly Part 1, Level of automation 2

Parameters:

Cycle time t_C	1,380 min/unit	number of units n	205565	unit/year
Shift time t_{SH}	394 min/shift			
Number of shifts n_S	3 shifts/day			
Working days d_W	240 days/year			
Personnel costs rate IE C_{P_IE}	77000 €/year			
Personnel costs rate master C_{P_M}	56000 €/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	45000 €/year			
Personnel costs rate depositor C_{P_D}	45000 €/year			
Period of depreciation a	7 years			
Total investment costs C_{INV_WOB}	19002600 €			
Total equipment costs C_{EQ_WOB}	390000 €/year			
Total investment costs $C_{INV\_Auto5000}$	8933700 €			
Total equipment costs $C_{EQ\_Auto5000}$	170000 €/year			
Total investment costs C_{INV_SA}	2843000 €			
Total equipment costs C_{EQ_SA}	146000 €/year			
Energy costs rate $C_{POW\_Auto5000}$	46 €/kW*year			
Energy costs rate $C_{W\_Auto5000}$	0,070 €/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWi}	c_{P_DWi}	t_{M_QCCi}	c_{P_QCCi}	t_{M_RWi}	c_{P_RWi}	t_{M_OWi}	c_{P_OWi}	t_{M_Di}	c_{P_Di}	n_{Mi}	c_{P_Mi}	c_{P_MAi}	c_{P_Pi}	c_{P_IEi}	C_{INVi}	c_{INVi}	P_{Ei}	c_{Ei}	c_{EQi}	P_{OSi}	c_{OSi}	
	$c_{P\_i} = \frac{t_{M\_i} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Di} = \frac{t_{M\_Di} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_M} = n_M \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAi} = c_{INVi} \cdot 0{,}5$	$c_{P\_Pi} = c_{INVi} \cdot 0.07$	$c_{P\_IEi} = \frac{\sum t_{Mi}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVi} = \frac{C_{INVi}}{a \cdot n}$		[illegible]	[illegible]		[illegible]	
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,06 €	0,0084 €	0,0005 €	176.000 €	0,12 €	20	0,037 €	0,018 €	1,5	0,003 €	0,72 €
Cleaning window flange, Closing tailgate	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,31 €	0,0434 €	0,0005 €	891.000 €	0,62 €	30	0,055 €	0,089 €	1	0,002 €	1,60 €
Priming window flange, Opening bonnet	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,40 €	0,0553 €	0,0005 €	1.141.000 €	0,79 €	30	0,055 €	0,114 €	1	0,002 €	1,90 €
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,13 €	0,0182 €	0,0005 €	371.000 €	0,26 €	10	0,018 €	0,037 €	1,5	0,003 €	0,94 €
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,55 €	0,0770 €	0,0005 €	1.586.000 €	1,10 €	60	0,110 €	0,158 €	4,5	0,008 €	2,50 €
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,55 €	0,0770 €	0,0005 €	1.586.000 €	1,10 €	60	0,110 €	0,158 €	4,5	0,008 €	2,50 €
Removing cable box, Remaining screw connections	2,325	1,11 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,119	0,10 €	0,06 €	0,0084 €	0,0014 €	176.000 €	0,12 €	1	0,002 €	0,018 €	1	0,002 €	1,55 €
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,16 €	0,0224 €	0,0005 €	461.000 €	0,32 €	10	0,018 €	0,046 €	1	0,002 €	1,04 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWi}	c_{P_DWi}	t_{M_QCCi}	c_{P_QCCi}	t_{M_RWi}	c_{P_RWi}	t_{M_OWi}	c_{P_OWi}	t_{M_Di}	c_{P_Di}	n_{Mi}	c_{P_Mi}	c_{P_MAi}	c_{P_Pi}	c_{P_IEi}	C_{INVi}	c_{INVi}	P_{Ei}	c_{Ei}	c_{EQi}	P_{OSi}	c_{OSi}	
	$c_{P\_i} = \frac{t_{M\_i} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Di} = \frac{t_{M\_Di} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_M} = n_M \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAi} = c_{INVi} \cdot 0{,}5$	$c_{P\_Pi} = c_{INVi} \cdot 0.07$	$c_{P\_IEi} = \frac{\sum t_{Mi}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVi} = \frac{C_{INVi}}{a \cdot n}$		[illegible]	[illegible]		[illegible]	
Rollforming tailgate	1,07	0,51 €	0,28	0,13 €	0	0,00 €	0	0,00 €	0	0,00 €	0,065	0,05 €	0,01 €	0,0014 €	0,0008 €	34.000 €	0,02 €	1	0,002 €	0,003 €	0,5	0,001 €	0,76 €
Rollforming doors	2,4	1,14 €	0,28	0,13 €	0	0,00 €	0	0,00 €	0	0,00 €	0,129	0,11 €	0,03 €	0,0035 €	0,0015 €	68.000 €	0,05 €	1	0,002 €	0,006 €	1	0,002 €	1,53 €
Total:	5,795		0,7		0,889		5,236		0		0,607												
Total net costs per unit:		2,76 €		0,33 €		0,42 €		2,52 €		0,00 €		0,47 €	2,26 €	0,32 €	0,01 €								
Total gross costs per unit (+4%):		2,87 €		0,34 €		0,44 €		2,62 €		0,00 €		0,49 €	2,35 €	0,33 €	0,01 €		4,50 €		0,41 €	0,65 €		0,03 €	

Total costs per unit: 15,04 €

Auto5000 GmbH, Assembly Part 1, Level of automation 3

Parameters:				
Cycle time t_C	1,380 min/unit	number of units n	205565	unit/year
Shift time t_{SH}	394 min/shift			
Number of shifts n_S	3 shifts/day			
Working days d_W	240 days/year			
Personnel costs rate IE C_{P_IE}	77000 €/year			
Personnel costs rate master C_{P_M}	56000 €/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	45000 €/year			
Personnel costs rate depositor C_{P_D}	45000 €/year			
Period of depreciation a	7 years			
Total investment costs C_{INV_WOB}	19002600 €			
Total equipment costs C_{EQ_WOB}	390000 €/year			
Total investment costs $C_{INV\_Auto5000}$	8933700 €			
Total equipment costs $C_{EQ\_Auto5000}$	170000 €/year			
Total investment costs C_{INV_SA}	2843000 €			
Total equipment costs C_{EQ_SA}	146000 €/year			
Energy costs rate $C_{POW\_Auto5000}$	46 €/kW*year			
Energy costs rate $C_{W\_Auto5000}$	0,070 €/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_...}}{n}+\frac{P_{OSj}\cdot C_{W\_...}\cdot t_C}{10\,min/h}$	
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,06 €	0,0084 €	0,0005 €	176.000 €	0,12 €	20	0,037 €	0,018 €	1,5	0,003 €	0,72 €
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,13 €	0,0182 €	0,0005 €	371.000 €	0,26 €	10	0,018 €	0,037 €	1,5	0,003 €	0,94 €
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,55 €	0,0770 €	0,0005 €	1.586.000 €	1,10 €	60	0,110 €	0,158 €	4,5	0,008 €	2,50 €
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,55 €	0,0770 €	0,0005 €	1.586.000 €	1,10 €	60	0,110 €	0,158 €	4,5	0,008 €	2,50 €
Removing cable box, Remaining screw connections	2,325	1,11 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,119	0,10 €	0,06 €	0,0084 €	0,0014 €	176.000 €	0,12 €	1	0,002 €	0,018 €	1	0,002 €	1,55 €
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,16 €	0,0224 €	0,0005 €	461.000 €	0,32 €	10	0,018 €	0,046 €	1	0,002 €	1,04 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_...}}{n}+\frac{P_{OSj}\cdot C_{W\_...}\cdot t_C}{10\,min/h}$	
Rollforming tailgate	1,07	0,51 €	0,28	0,13 €	0	0,00 €	0	0,00 €	0	0,00 €	0,065	0,05 €	0,01 €	0,0014 €	0,0008 €	34.000 €	0,02 €	1	0,002 €	0,003 €	0,5	0,001 €	0,76 €
Rollforming doors	2,4	1,14 €	0,28	0,13 €	0	0,00 €	0	0,00 €	0	0,00 €	0,129	0,11 €	0,03 €	0,0035 €	0,0015 €	68.000 €	0,05 €	1	0,002 €	0,006 €	1	0,002 €	1,53 €
Cleaning window flange, Closing tailgate	2,81	1,34 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,143	0,12 €	0,00 €	0,0000 €	0,0016 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	1,59 €
Priming window flange, Opening bonnet	2,81	1,34 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,143	0,12 €	0,00 €	0,0000 €	0,0016 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	1,59 €
Total:	11,415		0,98		0,635		3,74		0		0,809												
Total net costs per unit:		5,44 €		0,47 €		0,30 €		1,80 €		0,00 €		0,65 €	1,55 €	0,22 €	0,01 €								
Total gross costs per unit (+4%):		5,66 €		0,49 €		0,31 €		1,87 €		0,00 €		0,68 €	1,61 €	0,23 €	0,01 €		3,09 €		0,30 €	0,44 €		0,03 €	

Total costs per unit: 14,72 €

Auto5000 GmbH, Assembly Part 1, Level of automation 4

Parameters:

Cycle time t_C	**1,380** min/unit		number of units **n**	205565	unit/year
Shift time t_{SH}	**394** min/shift				
Number of shifts n_S	**3** shifts/day				
Working days d_W	**240** days/year				
Personnel costs rate IE C_{P_IE}	**77000** €/year				
Personnel costs rate master C_{P_M}	**56000** €/year				
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**45000** €/year				
Personnel costs rate depositor C_{P_D}	**45000** €/year				
Period of depreciation **a**	**7** years				
Total investment costs C_{INV_WOB}	**19002600** €				
Total equipment costs C_{EQ_WOB}	**390000** €/year				
Total investment costs $C_{INV\_Auto5000}$	**8933700** €				
Total equipment costs $C_{EQ\_Auto5000}$	**170000** €/year				
Total investment costs C_{INV_SA}	**2843000** €				
Total equipment costs C_{EQ_SA}	**146000** €/year				
Energy costs rate $C_{POW\_Auto5000}$	**46** €/kW*year				
Energy costs rate $C_{W\_Auto5000}$	**0,070** €/kWh				

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj} = n_{Mj}\cdot C_{P\_M}\cdot \frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj} = c_{INVj}\cdot 0{,}5$	$c_{P\_Pj} = c_{INVj}\cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a\cdot n}$		$c_{Ej} = \frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj}\cdot C_{POW\_Auto5000}}{n} + \frac{P_{OSj}\cdot C_{W\_Auto5000}\cdot t_C}{10 min/h}$	
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,06 €	0,748	0,36 €	0	0,00 €	0,042	0,03 €	0,13 €	0,0182 €	0,0005 €	371.000 €	0,26 €	10	0,018 €	0,037 €	1,5	0,003 €	0,94 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj} = n_{Mj}\cdot C_{P\_M}\cdot \frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj} = c_{INVj}\cdot 0{,}5$	$c_{P\_Pj} = c_{INVj}\cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a\cdot n}$		$c_{Ej} = \frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj}\cdot C_{POW\_Auto5000}}{n} + \frac{P_{OSj}\cdot C_{W\_Auto5000}\cdot t_C}{10 min/h}$	
Rollforming tailgate	1,07	0,51 €	0,28	0,13 €	0	0,00 €	0	0,00 €	0	0,00 €	0,065	0,05 €	0,01 €	0,0014 €	0,0008 €	34.000 €	0,02 €	1	0,002 €	0,003 €	0,5	0,001 €	0,76 €
Fitting cockpit location brackets	2,55	1,21 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,130	0,11 €	0,06 €	0,0084 €	0,0015 €	176.000 €	0,12 €	1	0,002 €	0,016 €	0,5	0,001 €	1,66 €
Rollforming doors	2,4	1,14 €	0,28	0,13 €	0	0,00 €	0	0,00 €	0	0,00 €	0,129	0,11 €	0,03 €	0,0035 €	0,0015 €	68.000 €	0,05 €	1	0,002 €	0,006 €	1	0,002 €	1,53 €
Cleaning window flange, Closing tailgate	2,81	1,34 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,143	0,12 €	0,00 €	0,0000 €	0,0016 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	1,59 €
Priming window flange, Opening bonnet	2,81	1,34 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,143	0,12 €	0,00 €	0,0000 €	0,0016 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	1,59 €
Cockpit fitting 1	3,906	1,86 €	0,41	0,20 €	0	0,00 €	0	0,00 €	0	0,00 €	0,209	0,17 €	0,28 €	0,0392 €	0,0024 €	805.500 €	0,56 €	65	0,119 €	0,075 €	5	0,009 €	3,42 €
Cockpit fitting 2	3,906	1,86 €	0,41	0,20 €	0	0,00 €	0	0,00 €	0	0,00 €	0,209	0,17 €	0,28 €	0,0392 €	0,0024 €	805.500 €	0,56 €	65	0,119 €	0,075 €	5	0,009 €	3,42 €
Total:	19,452		1,8		0,127		0,748		0		1,070												
Total net costs per unit:		9,26 €		0,87 €		0,06 €		0,36 €		0,00 €		0,88 €	0,79 €	0,11 €	0,01 €								
Total gross costs per unit (+4%):		9,63 €		0,90 €		0,06 €		0,37 €		0,00 €		0,92 €	0,82 €	0,11 €	0,01 €		1,57 €		0,26 €	0,21 €		0,03 €	

Total costs per unit: 14,91 €

Auto5000 GmbH, Assembly Part 1, Level of automation 5

Parameters:

Cycle time t_C	**1,380**	min/unit	number of units **n**	205565	unit/year
Shift time t_{SH}	**394**	min/shift			
Number of shifts n_S	**3**	shifts/day			
Working days d_W	**240**	days/year			
Personnel costs rate IE C_{P_IE}	**77000**	€/year			
Personnel costs rate master C_{P_M}	**56000**	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**45000**	€/year			
Personnel costs rate depositor C_{P_D}	**45000**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate $C_{POW\_Auto5000}$	**46**	€/kW*year			
Energy costs rate $C_{W\_Auto5000}$	**0,070**	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj} = n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj} = c_{INVj}\cdot 0,5$	$c_{P\_Pj} = c_{INVj}\cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a\cdot n}$		$c_{Ej} = \frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj}\cdot C_{POW\_Auto5000}}{n} + \frac{P_{OSj}\cdot C_{W\_Auto5000}\cdot t_C}{10 min/h}$	
Rollforming tailgate	**1,07**	0,51 €	**0,28**	0,13 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,065	0,05 €	0,01 €	0,0014 €	0,0008 €	**34.000 €**	0,02 €	**1**	0,002 €	0,003 €	**0,5**	0,001 €	0,76 €
Fitting cockpit location brackets	**2,55**	1,21 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,130	0,11 €	0,06 €	0,0084 €	0,0015 €	**176.000 €**	0,12 €	**1**	0,002 €	0,016 €	**0,5**	0,001 €	1,66 €
Rollforming doors	**2,4**	1,14 €	**0,28**	0,13 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,129	0,11 €	0,03 €	0,0035 €	0,0015 €	**68.000 €**	0,05 €	**1**	0,002 €	0,006 €	**1**	0,002 €	1,53 €
Cleaning window flange, Closing tailgate	**2,81**	1,34 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,143	0,12 €	0,00 €	0,0000 €	0,0016 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	1,59 €
Priming window flange, Opening bonnet	**2,81**	1,34 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,143	0,12 €	0,00 €	0,0000 €	0,0016 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	1,59 €

Stations with parameters that are taken from Golf A5 SA:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj} = n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj} = c_{INVj}\cdot 0,5$	$c_{P\_Pj} = c_{INVj}\cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a\cdot n}$		$c_{Ej} = \frac{P_{Ej}\cdot C_{POW\_SA}}{n} + \frac{P_{Ej}\cdot C_{W\_SA}\cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_SA}}\cdot C_{EQ\_SA}$		$c_{OSj} = \frac{P_{OSj}\cdot C_{POW\_SA}}{n} + \frac{P_{OSj}\cdot C_{W\_SA}\cdot t_C}{10 min/h}$	
Cockpit fitting	**14,9**	7,09 €	**0,55**	0,26 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,746	0,61 €	0,07 €	0,0091 €	0,0086 €	**192.000 €**	0,13 €	**11**	0,020 €	0,048 €	**3**	0,006 €	8,57 €

Total:	26,54		1,53		0		0		0		1,356											
Total net costs per unit:		12,63 €		0,73 €		0,00 €		0,00 €		0,00 €		1,12 €	0,17 €	0,02 €	0,02 €							
Total gross costs per unit (+4%):		13,14 €		0,76 €		0,00 €		0,00 €		0,00 €		1,16 €	0,18 €	0,02 €	0,02 €		0,32 €		0,03 €	0,07 €		0,01 €

Total costs per unit: 15,70 €

Auto5000 GmbH, Assembly Part 2, Level of automation 1

Parameters:

Cycle time t_C	**1,380**	min/unit	number of units **n**	205565	unit/year
Shift time t_{SH}	**394**	min/shift			
Number of shifts n_S	**3**	shifts/day			
Working days d_W	**240**	days/year			
Personnel costs rate IE C_{P_IE}	**77000**	€/year			
Personnel costs rate master C_{P_M}	**56000**	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**45000**	€/year			
Personnel costs rate depositor C_{P_D}	**45000**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate $C_{POW\_Auto5000}$	**46**	€/kW*year			
Energy costs rate $C_{W\_Auto5000}$	**0,070**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60\,min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_...}}{n} + \frac{P_{OSj} \cdot C_{W\_...} \cdot t_C}{10\,min/h}$	
Stamping VIN	**0**	0,00 €	**0**	0,00 €	**0,357**	0,17 €	**0,612**	0,29 €	**0**	0,00 €	0,047	0,04 €	0,32 €	0,0448 €	0,0005 €	**915.000 €**	0,64 €	**15**	0,028 €	0,091 €	**0,5**	0,001 €	1,66 €
Lifting up and fitting complete powertrain, Underbody work	**0**	0,00 €	**0**	0,00 €	**0,357**	0,17 €	**0,612**	0,29 €	**0**	0,00 €	0,047	0,04 €	0,90 €	0,1260 €	0,0005 €	**2.597.000 €**	1,80 €	**30**	0,055 €	0,259 €	**3**	0,006 €	3,71 €
Fitting gear shift	**0**	0,00 €	**0**	0,00 €	**0,357**	0,17 €	**0,612**	0,29 €	**0**	0,00 €	0,047	0,04 €	0,18 €	0,0252 €	0,0005 €	**523.000 €**	0,36 €	**8**	0,015 €	0,052 €	**0,5**	0,001 €	1,16 €
Closing bonnet	**0**	0,00 €	**0**	0,00 €	**0,357**	0,17 €	**0,612**	0,29 €	**0**	0,00 €	0,047	0,04 €	0,02 €	0,0021 €	0,0005 €	**40.000 €**	0,03 €	**1**	0,002 €	0,004 €	**0,5**	0,001 €	0,58 €
Lifting down fitting unit	**0**	0,00 €	**0**	0,00 €	**0,357**	0,17 €	**0,612**	0,29 €	**0**	0,00 €	0,047	0,04 €	0,20 €	0,0280 €	0,0005 €	**580.000 €**	0,40 €	**2**	0,004 €	0,058 €	**0**	0,000 €	1,22 €
Fitting rear glass/windscreen 1	**0**	0,00 €	**0**	0,00 €	**0,357**	0,17 €	**0,612**	0,29 €	**0,286**	0,14 €	0,061	0,05 €	0,23 €	0,0315 €	0,0007 €	**647.000 €**	0,45 €	**15**	0,028 €	0,065 €	**1**	0,002 €	1,49 €
Fitting rear glass/windscreen 2	**0**	0,00 €	**0**	0,00 €	**0,357**	0,17 €	**0,612**	0,29 €	**0,286**	0,14 €	0,061	0,05 €	0,23 €	0,0315 €	0,0007 €	**647.000 €**	0,45 €	**15**	0,028 €	0,065 €	**1**	0,002 €	1,49 €
Fitting side glasses	**0**	0,00 €	**0**	0,00 €	**0,357**	0,17 €	**0,612**	0,29 €	**0,572**	0,27 €	0,074	0,06 €	0,23 €	0,0315 €	0,0009 €	**647.000 €**	0,45 €	**25**	0,046 €	0,065 €	**1**	0,002 €	1,66 €
Total:	0		0		2,857		4,894		1,143		0,431												
Total net costs per unit:		0,00 €		0,00 €		1,36 €		2,32 €		0,55 €		0,36 €	2,31 €	0,32 €	0,00 €								
Total gross costs per unit (+4%):		0,00 €		0,00 €		1,41 €		2,41 €		0,57 €		0,37 €	2,40 €	0,33 €	0,00 €		4,58 €		0,21 €	0,66 €		0,02 €	

Total costs per unit: 12,97 €

Auto5000 GmbH, Assembly Part 2, Level of automation 2

Parameters:

Cycle time t_C	**1,380** min/unit	number of units **n**	205565	unit/year
Shift time t_{SH}	**394** min/shift			
Number of shifts n_S	**3** shifts/day			
Working days d_W	**240** days/year			
Personnel costs rate IE C_{P_IE}	**77000** €/year			
Personnel costs rate master C_{P_M}	**56000** €/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**45000** €/year			
Personnel costs rate depositor C_{P_D}	**45000** €/year			
Period of depreciation **a**	**7** years			
Total investment costs C_{INV_WOB}	**19002600** €			
Total equipment costs C_{EQ_WOB}	**390000** €/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700** €			
Total equipment costs $C_{EQ\_Auto5000}$	**170000** €/year			
Total investment costs C_{INV_SA}	**2843000** €			
Total equipment costs C_{EQ_SA}	**146000** €/year			
Energy costs rate $C_{POW\_Auto5000}$	**46** €/kW*year			
Energy costs rate $C_{W\_Auto5000}$	**0,070** €/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var}) t_{M_DWj}	c_{P_DWj}	QCC-workers (c_{var}) t_{M_QCCj}	c_{P_QCCj}	Reworker (c_{var}) t_{M_RWj}	c_{P_RWj}	Other workers (c_{var}) t_{M_OWj}	c_{P_OWj}	Depositor (c_{var}) t_{M_Dj}	c_{P_Dj}	Master (c_{var}) n_{Mj}	c_{P_Mj}	Maintenance & technical service (c_{fix}) c_{P_MAj}	Planning (c_{fix}) c_{P_Pj}	Industrial engineering (c_{fix}) c_{P_IEj}	Operating material: Capital investment (c_{fix}) C_{INVj}	c_{INVj}	Energy (c_{fix}) P_{Ej}	c_{Ej}	Equipment (c_{fix}) c_{EQj}	Material: Operating supplies (c_{fix}) P_{OSj}	c_{OSj}	Total per station (gross)
	$c_{P\_J} = \frac{t_{M\_J} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_M \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60\,min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{OSj} \cdot C_{W\_Auto5000} \cdot t_C}{10\,min/h}$	
Lifting up and fitting complete powertrain, Underbody work	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0	0,00 €	0,047	0,04 €	0,90 €	0,1260 €	0,0005 €	2.597.000 €	1,80 €	30	0,055 €	0,259 €	3	0,006 €	3,71 €
Fitting gear shift	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0	0,00 €	0,047	0,04 €	0,18 €	0,0252 €	0,0005 €	523.000 €	0,36 €	8	0,015 €	0,052 €	0,5	0,001 €	1,16 €
Closing bonnet	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0	0,00 €	0,047	0,04 €	0,02 €	0,0021 €	0,0005 €	40.000 €	0,03 €	1	0,002 €	0,004 €	0,5	0,001 €	0,58 €
Lifting down fitting unit	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0	0,00 €	0,047	0,04 €	0,20 €	0,0280 €	0,0005 €	580.000 €	0,40 €	2	0,004 €	0,058 €	0	0,000 €	1,22 €
Fitting rear glass/windscreen 1	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0,286	0,14 €	0,061	0,05 €	0,23 €	0,0315 €	0,0007 €	647.000 €	0,45 €	15	0,028 €	0,065 €	1	0,002 €	1,49 €
Fitting rear glass/windscreen 2	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0,286	0,14 €	0,061	0,05 €	0,23 €	0,0315 €	0,0007 €	647.000 €	0,45 €	15	0,028 €	0,065 €	1	0,002 €	1,49 €
Fitting side glasses	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0,572	0,27 €	0,074	0,06 €	0,23 €	0,0315 €	0,0009 €	647.000 €	0,45 €	25	0,046 €	0,065 €	1	0,002 €	1,66 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var}) t_{M_DWj}	c_{P_DWj}	QCC-workers (c_{var}) t_{M_QCCj}	c_{P_QCCj}	Reworker (c_{var}) t_{M_RWj}	c_{P_RWj}	Other workers (c_{var}) t_{M_OWj}	c_{P_OWj}	Depositor (c_{var}) t_{M_Dj}	c_{P_Dj}	Master (c_{var}) n_{Mj}	c_{P_Mj}	Maintenance & technical service (c_{fix}) c_{P_MAj}	Planning (c_{fix}) c_{P_Pj}	Industrial engineering (c_{fix}) c_{P_IEj}	Operating material: Capital investment (c_{fix}) C_{INVj}	c_{INVj}	Energy (c_{fix}) P_{Ej}	c_{Ej}	Equipment (c_{fix}) c_{EQj}	Material: Operating supplies (c_{fix}) P_{OSj}	c_{OSj}	Total per station (gross)
	$c_{P\_J} = \frac{t_{M\_J} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_M \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60\,min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{OSj} \cdot C_{W\_Auto5000} \cdot t_C}{10\,min/h}$	
Stamping VIN	2,3	1,09 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,118	0,10 €	0,22 €	0,0308 €	0,0014 €	636.000 €	0,44 €	5	0,009 €	0,059 €	3	0,006 €	2,09 €

	t_{M_DW}	c_{P_DW}	t_{M_QCC}	c_{P_QCC}	t_{M_RW}	c_{P_RW}	t_{M_OW}	c_{P_OW}	t_{M_D}	c_{P_D}	n_M	c_{P_M}	c_{P_MA}	c_{P_P}	c_{P_IE}	c_{INV}	c_E	c_{EQ}	c_{OS}
Total:	2,300		0,140		2,500		4,282		1,143		0,502								
Total net costs per unit:		1,09 €		0,07 €		1,19 €		2,03 €		0,55 €		0,42 €	2,21 €	0,31 €	0,01 €				
Total gross costs per unit (+4%):		1,13 €		0,07 €		1,24 €		2,11 €		0,57 €		0,44 €	2,30 €	0,32 €	0,01 €	4,38 €	0,19 €	0,63 €	0,02 €

Total costs per unit: 13,40 €

Auto5000 GmbH, Assembly Part 2, Level of automation 3

Parameters:

Cycle time t_C	1,380 min/unit	number of units n	205565	unit/year
Shift time t_{SH}	394 min/shift			
Number of shifts n_S	3 shifts/day			
Working days d_W	240 days/year			
Personnel costs rate IE C_{P_IE}	77000 €/year			
Personnel costs rate master C_{P_M}	56000 €/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	45000 €/year			
Personnel costs rate depositor C_{P_D}	45000 €/year			
Period of depreciation a	7 years			
Total investment costs C_{INV_WOB}	19002600 €			
Total equipment costs C_{EQ_WOB}	390000 €/year			
Total investment costs $C_{INV\_Auto5000}$	8933700 €			
Total equipment costs $C_{EQ\_Auto5000}$	170000 €/year			
Total investment costs C_{INV_SA}	2843000 €			
Total equipment costs C_{EQ_SA}	146000 €/year			
Energy costs rate $C_{POW\_Auto5000}$	46 €/kW*year			
Energy costs rate $C_{W\_Auto5000}$	0,070 €/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	$t_{M\ DWi}$	$c_{P\ DWi}$	$t_{M\ QCCi}$	$c_{P\ QCCi}$	$t_{M\ RWi}$	$c_{P\ RWi}$	$t_{M\ OWi}$	$c_{P\ OWi}$	$t_{M\ Di}$	$c_{P\ Di}$	n_{Mi}	$c_{P\ Mi}$	$c_{P\ MAi}$	$c_{P\ Pi}$	$c_{P\ IEi}$	C_{INVi}	c_{INVi}	P_{Ei}	c_{Ei}	c_{EQi}	P_{OSi}	c_{OSi}	
	$c_{P\_i}=\frac{t_{M\_i}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Di}=\frac{t_{M\_Di}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mi}=n_{Mi}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAi}=c_{INVi}\cdot 0{,}5$	$c_{P\_Pi}=c_{INVi}\cdot 0.07$	$c_{P\_IEi}=\frac{\sum t_{Mi}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVi}=\frac{C_{INVi}}{a\cdot n}$						
Lifting up and fitting complete powertrain, Underbody work	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0	0,00 €	0,047	0,04 €	0,90 €	0,1260 €	0,0005 €	2.597.000 €	1,80 €	30	0,055 €	0,259 €	3	0,006 €	3,71 €
Lifting down fitting unit	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0	0,00 €	0,047	0,04 €	0,20 €	0,0280 €	0,0005 €	580.000 €	0,40 €	2	0,004 €	0,058 €	0	0,000 €	1,22 €
Fitting rear glass/windscreen 1	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0,286	0,14 €	0,061	0,05 €	0,23 €	0,0315 €	0,0007 €	647.000 €	0,45 €	15	0,028 €	0,065 €	1	0,002 €	1,49 €
Fitting rear glass/windscreen 2	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0,286	0,14 €	0,061	0,05 €	0,23 €	0,0315 €	0,0007 €	647.000 €	0,45 €	15	0,028 €	0,065 €	1	0,002 €	1,49 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	$t_{M\ DWi}$	$c_{P\ DWi}$	$t_{M\ QCCi}$	$c_{P\ QCCi}$	$t_{M\ RWi}$	$c_{P\ RWi}$	$t_{M\ OWi}$	$c_{P\ OWi}$	$t_{M\ Di}$	$c_{P\ Di}$	n_{Mi}	$c_{P\ Mi}$	$c_{P\ MAi}$	$c_{P\ Pi}$	$c_{P\ IEi}$	C_{INVi}	c_{INVi}	P_{Ei}	c_{Ei}	c_{EQi}	P_{OSi}	c_{OSi}	
Stamping VIN	2,3	1,09 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,118	0,10 €	0,22 €	0,0308 €	0,0014 €	636.000 €	0,44 €	5	0,009 €	0,059 €	3	0,006 €	2,09 €
Fitting gear shift	1,2	0,57 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,065	0,05 €	0,01 €	0,0007 €	0,0007 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	0,74 €
Closing bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Fitting side glasses	1,252	0,60 €	0,55	0,26 €	0	0,00 €	0	0,00 €	0	0,00 €	0,087	0,07 €	0,11 €	0,0147 €	0,0010 €	297.000 €	0,21 €	10	0,018 €	0,027 €	1	0,002 €	1,35 €
Total:	4,752		0,830		1,429		2,447		0,572		0,486												
Total net costs per unit:		2,26 €		0,40 €		0,68 €		1,16 €		0,28 €		0,40 €	1,90 €	0,26 €	0,01 €								
Total gross costs per unit (+4%):		2,35 €		0,42 €		0,71 €		1,21 €		0,29 €		0,42 €	1,98 €	0,27 €	0,01 €		3,76 €		0,14 €	0,53 €		0,02 €	

Total costs per unit: 12,09 €

Auto5000 GmbH, Assembly Part 2, Level of automation 4

Parameters:

Cycle time t_C	1,380 min/unit		number of units n	205565 unit/year
Shift time t_{SH}	394 min/shift			
Number of shifts n_S	3 shifts/day			
Working days d_W	240 days/year			
Personnel costs rate IE C_{P_IE}	77000 €/year			
Personnel costs rate master C_{P_M}	56000 €/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	45000 €/year			
Personnel costs rate depositor C_{P_D}	45000 €/year			
Period of depreciation a	7 years			
Total investment costs C_{INV_WOB}	19002600 €			
Total equipment costs C_{EQ_WOB}	390000 €/year			
Total investment costs $C_{INV\_Auto5000}$	8933700 €			
Total equipment costs $C_{EQ\_Auto5000}$	170000 €/year			
Total investment costs C_{INV_SA}	2843000 €			
Total equipment costs C_{EQ_SA}	146000 €/year			
Energy costs rate $C_{POW\_Auto5000}$	46 €/kW*year			
Energy costs rate $C_{W\_Auto5000}$	0,070 €/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWi}	c_{P_DWi}	t_{M_QCCi}	c_{P_QCCi}	t_{M_RWi}	c_{P_RWi}	t_{M_OWi}	c_{P_OWi}	t_{M_Di}	c_{P_Di}	n_{Mi}	c_{P_Mi}	c_{P_MAi}	c_{P_Pi}	c_{P_IEi}	C_{INVi}	c_{INVi}	P_{Ei}	c_{Ei}	c_{EQi}	P_{OSi}	c_{OSi}	
	$c_{P\_j}=\frac{t_{M\_j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_W}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		[illegible]	[illegible]		[illegible]	
Lifting up and fitting complete powertrain, Underbody work	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0	0,00 €	0,047	0,04 €	0,90 €	0,1260 €	0,0005 €	2.597.000 €	1,80 €	30	0,055 €	0,259 €	3	0,006 €	3,71 €
Lifting down fitting unit	0	0,00 €	0	0,00 €	0,357	0,17 €	0,612	0,29 €	0	0,00 €	0,047	0,04 €	0,20 €	0,0280 €	0,0005 €	580.000 €	0,40 €	2	0,004 €	0,058 €	0	0,000 €	1,22 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWi}	c_{P_DWi}	t_{M_QCCi}	c_{P_QCCi}	t_{M_RWi}	c_{P_RWi}	t_{M_OWi}	c_{P_OWi}	t_{M_Di}	c_{P_Di}	n_{Mi}	c_{P_Mi}	c_{P_MAi}	c_{P_Pi}	c_{P_IEi}	C_{INVi}	c_{INVi}	P_{Ei}	c_{Ei}	c_{EQi}	P_{OSi}	c_{OSi}	
	$c_{P\_j}=\frac{t_{M\_j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_W}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		[illegible]	[illegible]		[illegible]	
Stamping VIN	2,3	1,09 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,118	0,10 €	0,22 €	0,0308 €	0,0014 €	636.000 €	0,44 €	5	0,009 €	0,059 €	3	0,006 €	2,09 €
Fitting gear shift	1,2	0,57 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,065	0,05 €	0,01 €	0,0007 €	0,0007 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	0,74 €
Closing bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Fitting rear glass/windscreen 1	3,2	1,52 €	0,55	0,26 €	0	0,00 €	0	0,00 €	0	0,00 €	0,181	0,15 €	0,14 €	0,0189 €	0,0021 €	394.000 €	0,27 €	20	0,037 €	0,036 €	1	0,002 €	2,52 €
Fitting side glasses	1,252	0,60 €	0,55	0,26 €	0	0,00 €	0	0,00 €	0	0,00 €	0,087	0,07 €	0,11 €	0,0147 €	0,0010 €	297.000 €	0,21 €	10	0,018 €	0,027 €	1	0,002 €	1,35 €
Total:	7,952		1,380		0,714		1,224		0,000		0,545												
Total net costs per unit:		3,78 €		0,66 €		0,34 €		0,58 €		0,00 €		0,45 €	1,58 €	0,22 €	0,01 €								
Total gross costs per unit (+4%):		3,93 €		0,69 €		0,35 €		0,60 €		0,00 €		0,47 €	1,64 €	0,23 €	0,01 €		3,13 €		0,13 €	0,44 €		0,02 €	

Total costs per unit: 11,63 €

Auto5000 GmbH, Assembly Part 2, Level of automation 5

Parameters:

Cycle time t_C	**1,380**	min/unit	number of units **n**	205565	unit/year
Shift time t_{SH}	**394**	min/shift			
Number of shifts n_S	**3**	shifts/day			
Working days d_W	**240**	days/year			
Personnel costs rate IE C_{P_IE}	**77000**	€/year			
Personnel costs rate master C_{P_M}	**56000**	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**45000**	€/year			
Personnel costs rate depositor C_{P_D}	**45000**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate $C_{POW\_Auto5000}$	**46**	€/kW*year			
Energy costs rate $C_{W\_Auto5000}$	**0,070**	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{OSj}\cdot C_{W\_Auto5000}\cdot t_C}{10min/h}$	
Stamping VIN	**2,3**	1,09 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,118	0,10 €	0,22 €	0,0308 €	0,0014 €	**636.000 €**	0,44 €	**5**	0,009 €	0,059 €	**3**	0,006 €	2,09 €
Fitting gear shift	**1,2**	0,57 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,065	0,05 €	0,01 €	0,0007 €	0,0007 €	**11.000 €**	0,01 €	**1**	0,002 €	0,001 €	**0,5**	0,001 €	0,74 €
Closing bonnet	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,00 €
Fitting rear glass/windscreen 1	**3,2**	1,52 €	**0,55**	0,26 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,181	0,15 €	0,14 €	0,0189 €	0,0021 €	**394.000 €**	0,27 €	**20**	0,037 €	0,036 €	**1**	0,002 €	2,52 €
Fitting side glasses	**1,252**	0,60 €	**0,55**	0,26 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,087	0,07 €	0,11 €	0,0147 €	0,0010 €	**297.000 €**	0,21 €	**10**	0,018 €	0,027 €	**1**	0,002 €	1,35 €

Stations with parameters that are taken from Golf A5 SA:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_SA}}\cdot C_{EQ\_SA}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{OSj}\cdot C_{W\_Auto5000}\cdot t_C}{10min/h}$	
Lifting up and fitting complete powertrain, Underbody work	**45,34**	21,58 €	**0,83**	0,39 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	2,230	1,82 €	0,21 €	0,0294 €	0,0257 €	**605.000 €**	0,42 €	**10**	0,018 €	0,151 €	**3**	0,006 €	25,61 €

Total:	53,292		2,210		0,000		0,000		0,000		2,681											
Total net costs per unit:		25,36 €		1,05 €		0,00 €		0,00 €		0,00 €		2,19 €	0,69 €	0,09 €	0,03 €							
Total gross costs per unit (+4%):		26,37 €		1,09 €		0,00 €		0,00 €		0,00 €		2,28 €	0,72 €	0,09 €	0,03 €		1,35 €		0,08 €	0,27 €		0,02 €

Total costs per unit: 32,31 €

Auto5000 GmbH, Assembly Part 3, Level of automation 1

Parameters:

Cycle time t_C	1,380	min/unit	number of units n	205565	unit/year
Shift time t_{SH}	394	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	240	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	56000	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	45000	€/year			
Personnel costs rate depositor C_{P_D}	45000	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate $C_{POW\_Auto5000}$	46	€/kW*year			
Energy costs rate $C_{W\_Auto5000}$	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Personnel costs

Station	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$
Opening bonnet	**0**	0,00 €	**0**	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0**	0,00 €	0,025	0,02 €	0,01 €	0,0007 €	0,0003 €
Putting in/Fitting CW trim panel	**0**	0,00 €	**0**	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0,572**	0,27 €	0,052	0,04 €	0,26 €	0,0357 €	0,0006 €
Putting in battery	**0**	0,00 €	**0**	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0,572**	0,27 €	0,052	0,04 €	0,15 €	0,0210 €	0,0006 €
Fitting battery	**0**	0,00 €	**0**	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0**	0,00 €	0,025	0,02 €	0,08 €	0,0105 €	0,0003 €
Fitting cross member	**0**	0,00 €	**0**	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0**	0,00 €	0,025	0,02 €	0,13 €	0,0182 €	0,0003 €
Fitting rear bumper	**0**	0,00 €	**0**	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0**	0,00 €	0,025	0,02 €	0,26 €	0,0357 €	0,0003 €
Fitting frontend	**0**	0,00 €	**0**	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0**	0,00 €	0,025	0,02 €	0,27 €	0,0378 €	0,0003 €
Placing spare wheel in boot	**0**	0,00 €	**0**	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0**	0,00 €	0,025	0,02 €	0,09 €	0,0119 €	0,0003 €
Premounting/Fitting wheels	**0**	0,00 €	**0**	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0**	0,00 €	0,025	0,02 €	0,42 €	0,0581 €	0,0003 €
Total:	0		0		2,286		2,286		1,143		0,279				
Total net costs per unit:		0,00 €		0,00 €		1,08 €		1,08 €		0,54 €		0,22 €	1,67 €	0,23 €	0,00 €
Total gross costs per unit (+4%):		0,00 €		0,00 €		1,12 €		1,12 €		0,56 €		0,23 €	1,74 €	0,24 €	0,00 €

Operating material / Material

Station	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		Total per station (gross)
	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_...}}{n} + \frac{P_{OSj} \cdot C_{W\_...} \cdot t_C}{60 min/h}$	
Opening bonnet	**17.600 €**	0,01 €	**8**	0,015 €	0,002 €	**0,5**	0,001 €	0,31 €
Putting in/Fitting CW trim panel	**731.000 €**	0,51 €	**10**	0,018 €	0,073 €	**1**	0,002 €	1,48 €
Putting in battery	**431.000 €**	0,30 €	**10**	0,018 €	0,043 €	**0,5**	0,001 €	1,11 €
Fitting battery	**210.000 €**	0,15 €	**8**	0,015 €	0,021 €	**1**	0,002 €	0,55 €
Fitting cross member	**373.000 €**	0,26 €	**15**	0,028 €	0,037 €	**1**	0,002 €	0,75 €
Fitting rear bumper	**733.000 €**	0,51 €	**10**	0,018 €	0,073 €	**0,5**	0,001 €	1,18 €
Fitting frontend	**777.000 €**	0,54 €	**30**	0,055 €	0,078 €	**1**	0,002 €	1,27 €
Placing spare wheel in boot	**242.000 €**	0,17 €	**10**	0,018 €	0,024 €	**0,5**	0,001 €	0,59 €
Premounting/Fitting wheels	**1.190.000 €**	0,83 €	**30**	0,055 €	0,119 €	**2**	0,004 €	1,78 €
Total:								
Total net costs per unit:								
Total gross costs per unit (+4%):		3,28 €		0,24 €	0,47 €		0,02 €	

Total costs per unit: 9,02 €

Auto5000 GmbH, Assembly Part 3, Level of automation 2

Parameters:

Cycle time t_C	**1,380** min/unit	number of units **n**	205565	unit/year
Shift time t_{SH}	**394** min/shift			
Number of shifts n_S	**3** shifts/day			
Working days d_W	**240** days/year			
Personnel costs rate IE C_{P_IE}	**77000** €/year			
Personnel costs rate master C_{P_M}	**56000** €/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**45000** €/year			
Personnel costs rate depositor C_{P_D}	**45000** €/year			
Period of depreciation **a**	**7** years			
Total investment costs C_{INV_WOB}	**19002600** €			
Total equipment costs C_{EQ_WOB}	**390000** €/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700** €			
Total equipment costs $C_{EQ\_Auto5000}$	**170000** €/year			
Total investment costs C_{INV_SA}	**2843000** €			
Total equipment costs C_{EQ_SA}	**146000** €/year			
Energy costs rate $C_{POW\_Auto5000}$	**46** €/kW*year			
Energy costs rate $C_{W\_Auto5000}$	**0,070** €/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var}) t_{M_DWj}	c_{P_DWj}	QCC-workers (c_{var}) t_{M_QCCj}	c_{P_QCCj}	Reworker (c_{var}) t_{M_RWj}	c_{P_RWj}	Other workers (c_{var}) t_{M_OWj}	c_{P_OWj}	Depositor (c_{var}) t_{M_Dj}	c_{P_Dj}	Master (c_{var}) n_{Mj}	c_{P_Mj}	Maintenance & technical service (c_{fix}) c_{P_MAj}	Planning (c_{fix}) c_{P_Pj}	Industrial engineering (c_{fix}) c_{P_IEj}	Operating material: Capital investment (c_{fix}) C_{INVj}	c_{INVj}	Energy (c_{fix}) P_{Ej}	c_{Ej}	Equipment (c_{fix}) c_{EQj}	Material: Operating supplies (c_{fix}) P_{OSj}	c_{OSj}	Total per station (gross)
	$c_{P\_\dots j}=\frac{t_{M\_\dots j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_W}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_...}}{n}+\frac{P_{OSj}\cdot C_{W\_...}\cdot t_C}{60 min/h}$	
Putting in battery	0	0,00 €	0	0,00 €	0,254	0,12 €	0,254	0,12 €	0,572	0,27 €	0,052	0,04 €	0,15 €	0,0210 €	0,0006 €	431.000 €	0,30 €	10	0,018 €	0,043 €	0,5	0,001 €	1,11 €
Fitting battery	0	0,00 €	0	0,00 €	0,254	0,12 €	0,254	0,12 €	0	0,00 €	0,025	0,02 €	0,08 €	0,0105 €	0,0003 €	210.000 €	0,15 €	8	0,015 €	0,021 €	1	0,002 €	0,55 €
Fitting cross member	0	0,00 €	0	0,00 €	0,254	0,12 €	0,254	0,12 €	0	0,00 €	0,025	0,02 €	0,13 €	0,0182 €	0,0003 €	373.000 €	0,26 €	15	0,028 €	0,037 €	1	0,002 €	0,75 €
Fitting rear bumper	0	0,00 €	0	0,00 €	0,254	0,12 €	0,254	0,12 €	0	0,00 €	0,025	0,02 €	0,26 €	0,0357 €	0,0003 €	733.000 €	0,51 €	10	0,018 €	0,073 €	0,5	0,001 €	1,18 €
Fitting frontend	0	0,00 €	0	0,00 €	0,254	0,12 €	0,254	0,12 €	0	0,00 €	0,025	0,02 €	0,27 €	0,0378 €	0,0003 €	777.000 €	0,54 €	30	0,055 €	0,078 €	1	0,002 €	1,27 €
Placing spare wheel in boot	0	0,00 €	0	0,00 €	0,254	0,12 €	0,254	0,12 €	0	0,00 €	0,025	0,02 €	0,09 €	0,0119 €	0,0003 €	242.000 €	0,17 €	10	0,018 €	0,024 €	0,5	0,001 €	0,59 €
Premounting/Fitting wheels	0	0,00 €	0	0,00 €	0,254	0,12 €	0,254	0,12 €	0	0,00 €	0,025	0,02 €	0,42 €	0,0581 €	0,0003 €	1.190.000 €	0,83 €	30	0,055 €	0,119 €	2	0,004 €	1,78 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var}) t_{M_DWj}	c_{P_DWj}	QCC-workers (c_{var}) t_{M_QCCj}	c_{P_QCCj}	Reworker (c_{var}) t_{M_RWj}	c_{P_RWj}	Other workers (c_{var}) t_{M_OWj}	c_{P_OWj}	Depositor (c_{var}) t_{M_Dj}	c_{P_Dj}	Master (c_{var}) n_{Mj}	c_{P_Mj}	Maintenance & technical service (c_{fix}) c_{P_MAj}	Planning (c_{fix}) c_{P_Pj}	Industrial engineering (c_{fix}) c_{P_IEj}	Operating material: Capital investment (c_{fix}) C_{INVj}	c_{INVj}	Energy (c_{fix}) P_{Ej}	c_{Ej}	Equipment (c_{fix}) c_{EQj}	Material: Operating supplies (c_{fix}) P_{OSj}	c_{OSj}	Total per station (gross)
	$c_{P\_\dots j}=\frac{t_{M\_\dots j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_W}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_...}}{n}+\frac{P_{OSj}\cdot C_{W\_...}\cdot t_C}{60 min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	2,29	1,09 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,117	0,10 €	0,01 €	0,0007 €	0,0014 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,34 €
Total:	2,290		0,140		1,778		1,778		0,572		0,319												
Total net costs per unit:		1,09 €		0,07 €		0,84 €		0,84 €		0,27 €		0,26 €	1,41 €	0,19 €	0,00 €								
Total gross costs per unit (+4%):		1,13 €		0,07 €		0,87 €		0,87 €		0,28 €		0,27 €	1,47 €	0,20 €	0,00 €		2,77 €		0,21 €	0,40 €		0,01 €	

Total costs per unit: 8,57 €

Auto5000 GmbH, Assembly Part 3, Level of automation 3

Parameters:

Cycle time t_C	**1,380** min/unit	number of units **n**	205565	unit/year
Shift time t_{SH}	**394** min/shift			
Number of shifts n_S	**3** shifts/day			
Working days d_W	**240** days/year			
Personnel costs rate IE C_{P_IE}	**77000** €/year			
Personnel costs rate master C_{P_M}	**56000** €/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**45000** €/year			
Personnel costs rate depositor C_{P_D}	**45000** €/year			
Period of depreciation **a**	**7** years			
Total investment costs C_{INV_WOB}	**19002600** €			
Total equipment costs C_{EQ_WOB}	**390000** €/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700** €			
Total equipment costs $C_{EQ\_Auto5000}$	**170000** €/year			
Total investment costs C_{INV_SA}	**2843000** €			
Total equipment costs C_{EQ_SA}	**146000** €/year			
Energy costs rate $C_{POW\_Auto5000}$	**46** €/kW*year			
Energy costs rate $C_{W\_Auto5000}$	**0,070** €/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var}) $t_{M\ DWI}$	$c_{P\ DWI}$	QCC-workers (c_{var}) $t_{M\ QCCI}$	$c_{P\ QCCI}$	Reworker (c_{var}) $t_{M\ RWI}$	$c_{P\ RWI}$	Other workers (c_{var}) $t_{M\ OWI}$	$c_{P\ OWI}$	Depositor (c_{var}) $t_{M\ DI}$	$c_{P\ DI}$	Master (c_{var}) n_{MI}	$c_{P\ MI}$	Maintenance & technical service (c_{fix}) $c_{P\ MAI}$ (·0,5)	Planning (c_{fix}) $c_{P\ PI}$ (·0.07)	Industrial engineering (c_{fix}) $c_{P\ IEI}$	Operating material: Capital investment (c_{fix}) C_{INVI}	c_{INVI}	Energy (c_{fix}) P_{EI}	c_{EI}	Equipment (c_{fix}) c_{EQI}	Material: Operating supplies (c_{fix}) P_{OSI}	c_{OSI}	Total per station (gross)
Putting in battery	0	0,00 €	0	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	**0,572**	0,27 €	0,052	0,04 €	0,15 €	0,0210 €	0,0006 €	**431.000 €**	0,30 €	**10**	0,018 €	0,043 €	**10**	0,018 €	1,13 €
Fitting battery	0	0,00 €	0	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	0	0,00 €	0,025	0,02 €	0,08 €	0,0105 €	0,0003 €	**210.000 €**	0,15 €	**8**	0,015 €	0,021 €	**8**	0,015 €	0,57 €
Fitting frontend	0	0,00 €	0	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	0	0,00 €	0,025	0,02 €	0,27 €	0,0378 €	0,0003 €	**777.000 €**	0,54 €	**30**	0,055 €	0,078 €	**30**	0,055 €	1,32 €
Placing spare wheel in boot	0	0,00 €	0	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	0	0,00 €	0,025	0,02 €	0,09 €	0,0119 €	0,0003 €	**242.000 €**	0,17 €	**10**	0,018 €	0,024 €	**10**	0,018 €	0,61 €
Premounting/Fitting wheels	0	0,00 €	0	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	0	0,00 €	0,025	0,02 €	0,42 €	0,0581 €	0,0003 €	**1.190.000 €**	0,83 €	**30**	0,055 €	0,119 €	**30**	0,055 €	1,83 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var}) $t_{M\ DWI}$	$c_{P\ DWI}$	QCC-workers (c_{var}) $t_{M\ QCCI}$	$c_{P\ QCCI}$	Reworker (c_{var}) $t_{M\ RWI}$	$c_{P\ RWI}$	Other workers (c_{var}) $t_{M\ OWI}$	$c_{P\ OWI}$	Depositor (c_{var}) $t_{M\ DI}$	$c_{P\ DI}$	Master (c_{var}) n_{MI}	$c_{P\ MI}$	Maintenance & technical service (c_{fix}) $c_{P\ MAI}$ (·0,5)	Planning (c_{fix}) $c_{P\ PI}$ (·0.07)	Industrial engineering (c_{fix}) $c_{P\ IEI}$	Operating material: Capital investment (c_{fix}) C_{INVI}	c_{INVI}	Energy (c_{fix}) P_{EI}	c_{EI}	Equipment (c_{fix}) c_{EQI}	Material: Operating supplies (c_{fix}) P_{OSI}	c_{OSI}	Total per station (gross)
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	**2,29**	1,09 €	**0,14**	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,117	0,10 €	0,01 €	0,0007 €	0,0014 €	**11.000 €**	0,01 €	1	0,002 €	0,001 €	1	0,002 €	1,34 €
Fitting cross member	**1,14**	0,54 €	**0,14**	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,062	0,05 €	0,01 €	0,0014 €	0,0007 €	**35.000 €**	0,02 €	1	0,002 €	0,003 €	1	0,002 €	0,73 €
Fitting rear bumper	**1,14**	0,54 €	**0,14**	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,062	0,05 €	0,01 €	0,0007 €	0,0007 €	**11.000 €**	0,01 €	1	0,002 €	0,001 €	1	0,002 €	0,71 €
Total:	4,570		0,420		1,270		1,270		0,572		0,393												
Total net costs per unit:		2,17 €		0,21 €		0,60 €		0,60 €		0,27 €		0,32 €	1,04 €	0,14 €	0,00 €								
Total gross costs per unit (+4%):		2,26 €		0,22 €		0,62 €		0,62 €		0,28 €		0,33 €	1,08 €	0,15 €	0,00 €		2,03 €		0,17 €	0,29 €		0,17 €	

Total costs per unit: 8,24 €

Auto5000 GmbH, Assembly Part 3, Level of automation 4

Parameters:

Cycle time t_C	**1,380**	min/unit	number of units **n**	205565	unit/year
Shift time t_{SH}	**394**	min/shift			
Number of shifts n_S	**3**	shifts/day			
Working days d_W	**240**	days/year			
Personnel costs rate IE C_{P_IE}	**77000**	€/year			
Personnel costs rate master C_{P_M}	**56000**	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**45000**	€/year			
Personnel costs rate depositor C_{P_D}	**45000**	€/year			
Period of depreciation **a**	**7**	years			
Total investment costs C_{INV_WOB}	**19002600**	€			
Total equipment costs C_{EQ_WOB}	**390000**	€/year			
Total investment costs $C_{INV\_Auto5000}$	**8933700**	€			
Total equipment costs $C_{EQ\_Auto5000}$	**170000**	€/year			
Total investment costs C_{INV_SA}	**2843000**	€			
Total equipment costs C_{EQ_SA}	**146000**	€/year			
Energy costs rate $C_{POW\_Auto5000}$	**46**	€/kW*year			
Energy costs rate $C_{W\_Auto5000}$	**0,070**	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_\dots j}=\frac{t_{M\_\dots j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	
Fitting frontend	0	0,00 €	0	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	0	0,00 €	0,025	0,02 €	0,27 €	0,0378 €	0,0003 €	**777.000 €**	0,54 €	**30**	0,055 €	0,078 €	**1**	0,002 €	1,27 €
Placing spare wheel in boot	0	0,00 €	0	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	0	0,00 €	0,025	0,02 €	0,09 €	0,0119 €	0,0003 €	**242.000 €**	0,17 €	**10**	0,018 €	0,024 €	**0,5**	0,001 €	0,59 €
Premounting/Fitting wheels	0	0,00 €	0	0,00 €	**0,254**	0,12 €	**0,254**	0,12 €	0	0,00 €	0,025	0,02 €	0,42 €	0,0581 €	0,0003 €	**1.190.000 €**	0,83 €	**30**	0,055 €	0,119 €	**2**	0,004 €	1,78 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_\dots j}=\frac{t_{M\_\dots j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{OSj}\cdot C_{W\_Auto5000}\cdot t_C}{60\,min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	**2,29**	1,09 €	**0,14**	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,117	0,10 €	0,01 €	0,0007 €	0,0014 €	**11.000 €**	0,01 €	1	0,002 €	0,001 €	**0,5**	0,001 €	1,34 €
Putting in/Fitting battery	**1,14**	0,54 €	**0,28**	0,13 €	0	0,00 €	0	0,00 €	0	0,00 €	0,069	0,06 €	0,03 €	0,0042 €	0,0008 €	**90.700 €**	0,06 €	5	0,009 €	0,008 €	**1,5**	0,003 €	0,88 €
Fitting cross member	**1,14**	0,54 €	**0,14**	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,062	0,05 €	0,01 €	0,0014 €	0,0007 €	**35.000 €**	0,02 €	1	0,002 €	0,003 €	**0,5**	0,001 €	0,72 €
Fitting rear bumper	**1,14**	0,54 €	**0,14**	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,062	0,05 €	0,01 €	0,0007 €	0,0007 €	**11.000 €**	0,01 €	1	0,002 €	0,001 €	**0,5**	0,001 €	0,71 €
Total:	5,710		0,700		0,763		0,763		0,000		0,385												
Total net costs per unit:		2,71 €		0,34 €		0,36 €		0,36 €		0,00 €		0,32 €	0,84 €	0,11 €	0,00 €								
Total gross costs per unit (+4%):		2,82 €		0,35 €		0,37 €		0,37 €		0,00 €		0,33 €	0,87 €	0,11 €	0,00 €		1,64 €		0,14 €	0,23 €		0,01 €	

Total costs per unit: 7,29 €

Auto5000 GmbH, Assembly Part 3, Level of automation 5

Parameters:

Cycle time t_C	1,380	min/unit	number of units n	205565	unit/year
Shift time t_{SH}	394	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	240	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	56000	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	45000	€/year			
Personnel costs rate depositor C_{P_D}	45000	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate $C_{POW\_Auto5000}$	46	€/kW*year			
Energy costs rate $C_{W\_Auto5000}$	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	$t_{M\ DWj}$	$c_{P\ DWj}$	$t_{M\ QCCj}$	$c_{P\ QCCj}$	$t_{M\ RWj}$	$c_{P\ RWj}$	$t_{M\ OWj}$	$c_{P\ OWj}$	$t_{M\ Dj}$	$c_{P\ Dj}$	n_{Mj}	$c_{P\ Mj}$	$c_{P\ MAj}$	$c_{P\ Pj}$	$c_{P\ IEj}$	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{OSj} \cdot C_{W\_Auto5000} \cdot t_C}{10 min/h}$	
Fitting frontend	0	0,00 €	0	0,00 €	0,254	0,12 €	0,254	0,12 €	0	0,00 €	0,025	0,02 €	0,27 €	0,0378 €	0,0003 €	777.000 €	0,54 €	30	0,055 €	0,078 €	1	0,002 €	1,27 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	$t_{M\ DWj}$	$c_{P\ DWj}$	$t_{M\ QCCj}$	$c_{P\ QCCj}$	$t_{M\ RWj}$	$c_{P\ RWj}$	$t_{M\ OWj}$	$c_{P\ OWj}$	$t_{M\ Dj}$	$c_{P\ Dj}$	n_{Mj}	$c_{P\ Mj}$	$c_{P\ MAj}$	$c_{P\ Pj}$	$c_{P\ IEj}$	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{OSj} \cdot C_{W\_Auto5000} \cdot t_C}{10 min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	2,29	1,09 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,117	0,10 €	0,01 €	0,0007 €	0,0014 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,34 €
Putting in/Fitting battery	1,14	0,54 €	0,28	0,13 €	0	0,00 €	0	0,00 €	0	0,00 €	0,069	0,06 €	0,03 €	0,0042 €	0,0008 €	90.700 €	0,06 €	5	0,009 €	0,008 €	1,5	0,003 €	0,88 €
Fitting cross member	1,14	0,54 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,062	0,05 €	0,01 €	0,0014 €	0,0007 €	35.000 €	0,02 €	1	0,002 €	0,003 €	0,5	0,001 €	0,72 €
Fitting rear bumper	1,14	0,54 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,062	0,05 €	0,01 €	0,0007 €	0,0007 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	0,71 €
Placing spare wheel in boot	0,728	0,35 €	0,14	0,07 €	0	0,00 €	0	0,00 €	0	0,00 €	0,042	0,03 €	0,03 €	0,0035 €	0,0005 €	70.000 €	0,05 €	5	0,009 €	0,006 €	0,5	0,001 €	0,57 €
Premounting/Fitting wheels	3,935	1,87 €	0,97	0,46 €	0	0,00 €	0	0,00 €	0	0,00 €	0,237	0,19 €	0,36 €	0,0497 €	0,0027 €	1.020.000 €	0,71 €	15	0,028 €	0,094 €	1,5	0,003 €	3,88 €
Total:	10,373		1,810		0,254		0,254		0,000		0,614												
Total net costs per unit:		4,93 €		0,87 €		0,12 €		0,12 €		0,00 €		0,50 €	0,72 €	0,10 €	0,01 €								
Total gross costs per unit (+4%):		5,13 €		0,90 €		0,12 €		0,12 €		0,00 €		0,52 €	0,75 €	0,10 €	0,01 €		1,40 €		0,11 €	0,19 €		0,01 €	

Total costs per unit: 9,37 €

Auto5000 GmbH, Assembly Part 3, Level of automation 6

Parameters:

Cycle time t_C	**1,380** min/unit		number of units **n**	205565	unit/year
Shift time t_{SH}	**394** min/shift				
Number of shifts n_S	**3** shifts/day				
Working days d_W	**240** days/year				
Personnel costs rate IE C_{P_IE}	**77000** €/year				
Personnel costs rate master C_{P_M}	**56000** €/year				
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	**45000** €/year				
Personnel costs rate depositor C_{P_D}	**45000** €/year				
Period of depreciation **a**	**7** years				
Total investment costs C_{INV_WOB}	**19002600** €				
Total equipment costs C_{EQ_WOB}	**390000** €/year				
Total investment costs $C_{INV\_Auto5000}$	**8933700** €				
Total equipment costs $C_{EQ\_Auto5000}$	**170000** €/year				
Total investment costs C_{INV_SA}	**2843000** €				
Total equipment costs C_{EQ_SA}	**146000** €/year				
Energy costs rate $C_{POW\_Auto5000}$	**46** €/kW*year				
Energy costs rate $C_{W\_Auto5000}$	**0,070** €/kWh				

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_..j} = \frac{t_{M\_..j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{OSj} \cdot C_{W\_Auto5000} \cdot t_C}{10 min/h}$	
Opening bonnet	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,00 €
Putting in/Fitting CW trim panel	**2,29**	1,09 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,117	0,10 €	0,01 €	0,0007 €	0,0014 €	**11.000 €**	0,01 €	**1**	0,002 €	0,001 €	**0,5**	0,001 €	1,34 €
Putting in/Fitting battery	**1,14**	0,54 €	**0,28**	0,13 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,069	0,06 €	0,03 €	0,0042 €	0,0008 €	**90.700 €**	0,06 €	**5**	0,009 €	0,008 €	**1,5**	0,003 €	0,88 €
Fitting cross member	**1,14**	0,54 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,062	0,05 €	0,01 €	0,0014 €	0,0007 €	**35.000 €**	0,02 €	**1**	0,002 €	0,003 €	**0,5**	0,001 €	0,72 €
Fitting rear bumper	**1,14**	0,54 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,062	0,05 €	0,01 €	0,0007 €	0,0007 €	**11.000 €**	0,01 €	**1**	0,002 €	0,001 €	**0,5**	0,001 €	0,71 €
Fitting frontend	**6,86**	3,26 €	**0,56**	0,27 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,358	0,29 €	0,36 €	0,0504 €	0,0041 €	**1.040.000 €**	0,72 €	**60**	0,110 €	0,096 €	**1,5**	0,003 €	5,33 €
Placing spare wheel in boot	**0,728**	0,35 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,042	0,03 €	0,03 €	0,0035 €	0,0005 €	**70.000 €**	0,05 €	**5**	0,009 €	0,006 €	**0,5**	0,001 €	0,57 €
Premounting/Fitting wheels	**3,935**	1,87 €	**0,97**	0,46 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,237	0,19 €	0,36 €	0,0497 €	0,0027 €	**1.020.000 €**	0,71 €	**15**	0,028 €	0,094 €	**1,5**	0,003 €	3,88 €
Total:	17,233		2,370		0,000		0,000		0,000		0,947												
Total net costs per unit:		8,19 €		1,14 €		0,00 €		0,00 €		0,00 €		0,77 €	0,81 €	0,11 €	0,01 €								
Total gross costs per unit (+4%):		8,52 €		1,19 €		0,00 €		0,00 €		0,00 €		0,80 €	0,84 €	0,11 €	0,01 €		1,58 €		0,16 €	0,21 €		0,01 €	

Total costs per unit: 13,43 €

Auto5000 GmbH, Assembly Part 3, Level of automation 7

Parameters:

Cycle time t_C	1,380	min/unit	number of units n	205565	unit/year
Shift time t_{SH}	394	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	240	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	56000	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	45000	€/year			
Personnel costs rate depositor C_{P_D}	45000	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate $C_{POW\_Auto5000}$	46	€/kW*year			
Energy costs rate $C_{W\_Auto5000}$	0,070	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWi}	c_{P_DWi}	t_{M_QCCi}	c_{P_QCCi}	t_{M_RWi}	c_{P_RWi}	t_{M_OWi}	c_{P_OWi}	t_{M_Di}	c_{P_Di}	n_{Mi}	c_{P_Mi}	c_{P_MAi}	c_{P_Pi}	c_{P_IEi}	C_{INVi}	c_{INVi}	P_{Ei}	c_{Ei}	c_{EQi}	P_{OSi}	c_{OSi}	
	$c_{P\_Ji} = \frac{t_{M\_Ji} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Di} = \frac{t_{M\_Di} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mi} = n_{Mi} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAi} = c_{INVi} \cdot 0{,}5$	$c_{P\_Pi} = c_{INVi} \cdot 0{,}07$	$c_{P\_IEi} = \frac{\sum t_{Mi}}{2} \cdot \frac{d_{WW}}{d_W} \cdot \frac{C_{P\_IE}}{a \cdot n}$		$c_{INVi} = \frac{C_{INVi}}{a \cdot n}$						
Opening bonnet	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,00 €
Putting in/Fitting CW trim panel	**2,29**	1,09 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,117	0,10 €	0,01 €	0,0007 €	0,0014 €	**11.000 €**	0,01 €	**1**	0,002 €	0,001 €	**0,5**	0,001 €	1,34 €
Fitting cross member	**1,14**	0,54 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,062	0,05 €	0,01 €	0,0014 €	0,0007 €	**35.000 €**	0,02 €	**1**	0,002 €	0,003 €	**0,5**	0,001 €	0,72 €
Fitting rear bumper	**1,14**	0,54 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,062	0,05 €	0,01 €	0,0007 €	0,0007 €	**11.000 €**	0,01 €	**1**	0,002 €	0,001 €	**0,5**	0,001 €	0,71 €

Stations with parameters that are taken from Golf A5 SA:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWi}	c_{P_DWi}	t_{M_QCCi}	c_{P_QCCi}	t_{M_RWi}	c_{P_RWi}	t_{M_OWi}	c_{P_OWi}	t_{M_Di}	c_{P_Di}	n_{Mi}	c_{P_Mi}	c_{P_MAi}	c_{P_Pi}	c_{P_IEi}	C_{INVi}	c_{INVi}	P_{Ei}	c_{Ei}	c_{EQi}	P_{OSi}	c_{OSi}	
	$c_{P\_Ji} = \frac{t_{M\_Ji} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Di} = \frac{t_{M\_Di} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mi} = n_{Mi} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAi} = c_{INVi} \cdot 0{,}5$	$c_{P\_Pi} = c_{INVi} \cdot 0{,}07$	$c_{P\_IEi} = \frac{\sum t_{Mi}}{2} \cdot \frac{d_{WW}}{d_W} \cdot \frac{C_{P\_IE}}{a \cdot n}$		$c_{INVi} = \frac{C_{INVi}}{a \cdot n}$			$c_{EQi} = \frac{1}{n} \cdot \frac{C_{INVi}}{C_{INV\_SA}} \cdot C_{EQ\_SA}$			
Putting in/Fitting battery	**1,38**	0,66 €	**0,28**	0,13 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,080	0,07 €	0,01 €	0,0007 €	0,0009 €	**20.000 €**	0,01 €	**1**	0,002 €	0,005 €	**0,5**	0,001 €	0,92 €
Fitting frontend	**8,6**	4,09 €	**0,56**	0,27 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,443	0,36 €	0,08 €	0,0112 €	0,0051 €	**225.000 €**	0,16 €	**10**	0,018 €	0,056 €	**1**	0,002 €	5,24 €
Placing spare wheel in boot	**0,68**	0,32 €	**0,14**	0,07 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,040	0,03 €	0,00 €	0,0000 €	0,0005 €	**0 €**	0,00 €	**0**	0,000 €	0,000 €	**0**	0,000 €	0,44 €
Premounting/Fitting wheels	**6,64**	3,16 €	**0,97**	0,46 €	**0**	0,00 €	**0**	0,00 €	**0**	0,00 €	0,368	0,30 €	0,19 €	0,0266 €	0,0042 €	**550.000 €**	0,38 €	**5**	0,009 €	0,137 €	**1**	0,002 €	4,83 €
Total:	21,870		2,370		0,000		0,000		0,000		1,172												
Total net costs per unit:		10,40 €		1,14 €		0,00 €		0,00 €		0,00 €		0,96 €	0,31 €	0,04 €	0,01 €								
Total gross costs per unit (+4%):		10,82 €		1,19 €		0,00 €		0,00 €		0,00 €		1,00 €	0,32 €	0,04 €	0,01 €		0,59 €		0,04 €	0,20 €		0,01 €	

Total costs per unit: 14,20 €

Appendix F

Tables Auto5000 GmbH Wolfsburg:

Calculation of total costs per unit
for each level of automation

Golf A5 Wolfsburg, Assembly Part 1, Level of automation 1

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Personnel costs

Station	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$
Rollforming tailgate	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,15 €	0,0210 €	0,0005 €
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,07 €	0,0091 €	0,0005 €
Rollforming doors	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,35 €	0,0483 €	0,0005 €
Cleaning window flange, Closing tailgate	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,34 €	0,0469 €	0,0005 €
Priming window flange, Opening bonnet	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,43 €	0,0602 €	0,0005 €
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,14 €	0,0196 €	0,0005 €
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,60 €	0,0833 €	0,0005 €
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,60 €	0,0833 €	0,0005 €
Removing cable box, Remaining screw connections	2,325	1,78 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,144	0,17 €	0,07 €	0,0091 €	0,0015 €
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,18 €	0,0245 €	0,0005 €
Total:	2,325		0,14		1,143		6,732		0		0,603				
Total net costs per unit:		1,78 €		0,11 €		0,90 €		5,13 €		0,00 €		0,71 €	2,93 €	0,41 €	0,01 €
Total gross costs per unit (+11%):		1,98 €		0,12 €		1,00 €		5,69 €		0,00 €		0,79 €	3,25 €	0,46 €	0,01 €

Operating material, Material

Station	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		Total per station (gross)
	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Rollforming tailgate	396.000 €	0,30 €	10	0,016 €	0,043 €	0,5	0,001 €	1,36 €
Fitting cockpit location brackets	176.000 €	0,13 €	20	0,032 €	0,019 €	1,5	0,002 €	1,08 €
Rollforming doors	918.000 €	0,69 €	40	0,063 €	0,099 €	1	0,002 €	2,11 €
Cleaning window flange, Closing tailgate	891.000 €	0,67 €	30	0,047 €	0,096 €	1	0,002 €	2,06 €
Priming window flange, Opening bonnet	1.141.000 €	0,86 €	30	0,047 €	0,123 €	1	0,002 €	2,39 €
Applying cockpit glue	371.000 €	0,28 €	10	0,016 €	0,040 €	1,5	0,002 €	1,33 €
Cockpit fitting 1	1.586.000 €	1,19 €	60	0,095 €	0,171 €	4,5	0,007 €	3,03 €
Cockpit fitting 2	1.586.000 €	1,19 €	60	0,095 €	0,171 €	4,5	0,007 €	3,03 €
Removing cable box, Remaining screw connections	176.000 €	0,13 €	1	0,002 €	0,019 €	1	0,002 €	2,53 €
Remaining screw connections	461.000 €	0,35 €	10	0,016 €	0,050 €	1	0,002 €	1,46 €
Total gross costs per unit (+11%):		5,79 €		0,43 €	0,83 €		0,03 €	

Total costs per unit: 20,38 €

Golf A5 Wolfsburg, Assembly Part 1, Level of automation 2

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	$t_{M\ DWj}$	$c_{P\ DWj}$	$t_{M\ QCCj}$	$c_{P\ QCCj}$	$t_{M\ RWj}$	$c_{P\ RWj}$	$t_{M\ OWj}$	$c_{P\ OWj}$	$t_{M\ Dj}$	$c_{P\ Dj}$	n_{Mj}	$c_{P\ Mj}$	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60\ min/\ h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\ min/\ h}$	
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,07 €	0,0091 €	0,0005 €	176.000 €	0,13 €	20	0,032 €	0,019 €	1,5	0,002 €	1,08 €
Cleaning window flange, Closing tailgate	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,34 €	0,0469 €	0,0005 €	891.000 €	0,67 €	30	0,047 €	0,096 €	1	0,002 €	2,06 €
Priming window flange, Opening bonnet	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,43 €	0,0602 €	0,0005 €	1.141.000 €	0,86 €	30	0,047 €	0,123 €	1	0,002 €	2,39 €
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,14 €	0,0196 €	0,0005 €	371.000 €	0,28 €	10	0,016 €	0,040 €	1,5	0,002 €	1,33 €
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,60 €	0,0833 €	0,0005 €	1.586.000 €	1,19 €	60	0,095 €	0,171 €	4,5	0,007 €	3,03 €
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,60 €	0,0833 €	0,0005 €	1.586.000 €	1,19 €	60	0,095 €	0,171 €	4,5	0,007 €	3,03 €
Removing cable box, Remaining screw connections	2,325	1,78 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,144	0,17 €	0,07 €	0,0091 €	0,0015 €	176.000 €	0,13 €	1	0,002 €	0,019 €	1	0,002 €	2,53 €
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,18 €	0,0245 €	0,0005 €	461.000 €	0,35 €	10	0,016 €	0,050 €	1	0,002 €	1,46 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	$t_{M\ DWj}$	$c_{P\ DWj}$	$t_{M\ QCCj}$	$c_{P\ QCCj}$	$t_{M\ RWj}$	$c_{P\ RWj}$	$t_{M\ OWj}$	$c_{P\ OWj}$	$t_{M\ Dj}$	$c_{P\ Dj}$	n_{Mj}	$c_{P\ Mj}$	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60\ min/\ h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\ min/\ h}$	
Rollforming tailgate	1,07	0,82 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,079	0,09 €	0,02 €	0,0021	0,0008 €	34.000 €	0,03 €	1	0,002 €	0,003 €	0,5	0,001 €	1,30 €
Rollforming doors	2,4	1,83 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,156	0,18 €	0,03 €	0,0035	0,0017 €	68.000 €	0,05 €	1	0,002 €	0,007 €	1	0,002 €	2,56 €
Total:	5,795		0,7		0,889		5,236		0		0,736												
Total net costs per unit:		4,43 €		0,53 €		0,70 €		3,99 €		0,00 €		0,86 €	2,48 €	0,34 €	0,01 €								
Total gross costs per unit (+11%):		4,92 €		0,59 €		0,78 €		4,43 €		0,00 €		0,95 €	2,75 €	0,38 €	0,01 €		4,88 €		0,35 €	0,70 €		0,03 €	

Total costs per unit: 20,77 €

Golf A5 Wolfsburg, Assembly Part 1, Level of automation 3

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Fitting cockpit location brackets	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,07 €	0,0091 €	0,0005 €	176.000 €	0,13 €	20	0,032 €	0,019 €	1,5	0,002 €	1,08 €
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,14 €	0,0196 €	0,0005 €	371.000 €	0,28 €	10	0,016 €	0,040 €	1,5	0,002 €	1,33 €
Cockpit fitting 1	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,60 €	0,0833 €	0,0005 €	1.586.000 €	1,19 €	60	0,095 €	0,171 €	4,5	0,007 €	3,03 €
Cockpit fitting 2	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,60 €	0,0833 €	0,0005 €	1.586.000 €	1,19 €	60	0,095 €	0,171 €	4,5	0,007 €	3,03 €
Removing cable box, Remaining screw connections	2,325	1,78 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,144	0,17 €	0,07 €	0,0091 €	0,0015 €	176.000 €	0,13 €	1	0,002 €	0,019 €	1	0,002 €	2,53 €
Remaining screw connections	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,18 €	0,0245 €	0,0005 €	461.000 €	0,35 €	10	0,016 €	0,050 €	1	0,002 €	1,46 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Rollforming tailgate	1,07	0,82 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,079	0,09 €	0,02 €	0,0021 €	0,0008 €	34.000 €	0,03 €	1	0,002 €	0,003 €	0,5	0,001 €	1,30 €
Rollforming doors	2,4	1,83 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,156	0,18 €	0,03 €	0,0035 €	0,0017 €	68.000 €	0,05 €	1	0,002 €	0,007 €	1	0,002 €	2,56 €
Cleaning window flange, Closing tailgate	2,81	2,15 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,172	0,20 €	0,00 €	0,0000 €	0,0018 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	2,73 €
Priming window flange, Opening bonnet	2,81	2,15 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,172	0,20 €	0,00 €	0,0000 €	0,0018 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	2,73 €
Total:	11,415		0,98		0,635		3,74		0		0,978												
Total net costs per unit:		8,73 €		0,75 €		0,50 €		2,85 €		0,00 €		1,14 €	1,71 €	0,23 €	0,01 €								
Total gross costs per unit (+11%):		9,69 €		0,83 €		0,56 €		3,16 €		0,00 €		1,27 €	1,90 €	0,26 €	0,01 €		3,35 €		0,26 €	0,48 €		0,03 €	

Total costs per unit: 21,78 €

Golf A5 Wolfsburg, Assembly Part 1, Level of automation 4

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60\ min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\ min/h}$	
Applying cockpit glue	0	0,00 €	0	0,00 €	0,127	0,10 €	0,748	0,57 €	0	0,00 €	0,051	0,06 €	0,14 €	0,0196 €	0,0005 €	371.000 €	0,28 €	10	0,016 €	0,040 €	1,5	0,002 €	1,33 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60\ min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\ min/h}$	
Rollforming tailgate	1,07	0,82 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,079	0,09 €	0,02 €	0,0021 €	0,0008 €	34.000 €	0,03 €	1	0,002 €	0,003 €	0,5	0,001 €	1,30 €
Fitting cockpit location brackets	2,55	1,95 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,157	0,18 €	0,07 €	0,0091 €	0,0017 €	176.000 €	0,13 €	1	0,002 €	0,018 €	0,5	0,001 €	2,73 €
Rollforming doors	2,4	1,83 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,156	0,18 €	0,03 €	0,0035 €	0,0017 €	68.000 €	0,05 €	1	0,002 €	0,007 €	1	0,002 €	2,56 €
Cleaning window flange, Closing tailgate	2,81	2,15 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,172	0,20 €	0,00 €	0,0000 €	0,0018 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	2,73 €
Priming window flange, Opening bonnet	2,81	2,15 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,172	0,20 €	0,00 €	0,0000 €	0,0018 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	2,73 €
Cockpit fitting 1	3,906	2,98 €	0,41	0,31 €	0	0,00 €	0	0,00 €	0	0,00 €	0,252	0,30 €	0,30 €	0,0420 €	0,0027 €	805.500 €	0,60 €	65	0,102 €	0,081 €	5	0,008 €	5,16 €
Cockpit fitting 2	3,906	2,98 €	0,41	0,31 €	0	0,00 €	0	0,00 €	0	0,00 €	0,252	0,30 €	0,30 €	0,0420 €	0,0027 €	805.500 €	0,60 €	65	0,102 €	0,081 €	5	0,008 €	5,16 €
Total:	19,452		1,8		0,127		0,748		0		1,291												
Total net costs per unit:		14,86 €		1,37 €		0,10 €		0,57 €		0,00 €		1,51 €	0,86 €	0,12 €	0,01 €								
Total gross costs per unit (+11%):		16,49 €		1,52 €		0,11 €		0,63 €		0,00 €		1,68 €	0,95 €	0,13 €	0,02 €		1,69 €		0,23 €	0,23 €		0,02 €	

Total costs per unit: 23,70 €

Golf A5 Wolfsburg, Assembly Part 1, Level of automation 5

Parameters:					
Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60\,min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\,min/h}$	
Rollforming tailgate	1,07	0,82 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,079	0,09 €	0,02 €	0,0021 €	0,0008 €	34.000 €	0,03 €	1	0,002 €	0,003 €	0,5	0,001 €	1,30 €
Fitting cockpit location brackets	2,55	1,95 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,157	0,18 €	0,07 €	0,0091 €	0,0017 €	176.000 €	0,13 €	1	0,002 €	0,018 €	0,5	0,001 €	2,73 €
Rollforming doors	2,4	1,83 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,156	0,18 €	0,03 €	0,0035 €	0,0017 €	68.000 €	0,05 €	1	0,002 €	0,007 €	1	0,002 €	2,56 €
Cleaning window flange, Closing tailgate	2,81	2,15 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,172	0,20 €	0,00 €	0,0000 €	0,0018 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	2,73 €
Priming window flange, Opening bonnet	2,81	2,15 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,172	0,20 €	0,00 €	0,0000 €	0,0018 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	2,73 €

Stations with parameters that are taken from Golf A5 SA:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_SA}}{n} + \frac{P_{Ej} \cdot C_{W\_SA} \cdot t_C}{60\,min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_SA}} \cdot C_{EQ\_SA}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\,min/h}$	
Cockpit fitting	14,9	11,38 €	0,55	0,42 €	0	0,00 €	0	0,00 €	0	0,00 €	0,901	1,06 €	0,07 €	0,0098 €	0,0097 €	192.000 €	0,14 €	11	0,017 €	0,052 €	3	0,005 €	14,59 €

	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}
Total:	26,54		1,53		0		0		0		1,637											
Total net costs per unit:		20,28 €		1,17 €		0,00 €		0,00 €		0,00 €		1,91 €	0,19 €	0,02 €	0,02 €							
Total gross costs per unit (+11%):		22,51 €		1,30 €		0,00 €		0,00 €		0,00 €		2,12 €	0,21 €	0,02 €	0,02 €		0,35 €		0,02 €	0,08 €		0,01 €

Total costs per unit: 26,64 €

Golf A5 Wolfsburg, Assembly Part 2, Level of automation 1

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Stamping VIN	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,35 €	0,0483 €	0,0006 €	915.000 €	0,69 €	15	0,024 €	0,099 €	0,5	0,001 €	2,16 €
Lifting up and fitting complete powertrain, Underbody work	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,98 €	0,1365 €	0,0006 €	2.597.000 €	1,95 €	30	0,047 €	0,280 €	3	0,005 €	4,42 €
Fitting gear shift	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,20 €	0,0273 €	0,0006 €	523.000 €	0,39 €	8	0,013 €	0,056 €	0,5	0,001 €	1,61 €
Closing bonnet	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,02 €	0,0021 €	0,0006 €	40.000 €	0,03 €	1	0,002 €	0,004 €	0,5	0,001 €	0,96 €
Lifting down fitting unit	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,22 €	0,0308 €	0,0006 €	580.000 €	0,44 €	2	0,003 €	0,063 €	0	0,000 €	1,68 €
Fitting rear glass/windscreen 1	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0,286	0,20 €	0,073	0,09 €	0,25 €	0,0343 €	0,0008 €	647.000 €	0,49 €	15	0,024 €	0,070 €	1	0,002 €	2,05 €
Fitting rear glass/windscreen 2	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0,286	0,20 €	0,073	0,09 €	0,25 €	0,0343 €	0,0008 €	647.000 €	0,49 €	15	0,024 €	0,070 €	1	0,002 €	2,05 €
Fitting side glasses	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0,572	0,39 €	0,090	0,11 €	0,25 €	0,0343 €	0,0010 €	647.000 €	0,49 €	25	0,039 €	0,070 €	1	0,002 €	2,29 €
Total:	0		0		2,857		4,894		1,143		0,521												
Total net costs per unit:		0,00 €		0,00 €		2,16 €		3,76 €		0,79 €		0,64 €	2,52 €	0,35 €	0,01 €								
Total gross costs per unit (+11%):		0,00 €		0,00 €		2,40 €		4,17 €		0,88 €		0,71 €	2,80 €	0,39 €	0,01 €		4,97 €		0,18 €	0,71 €		0,01 €	

Total costs per unit: 17,22 €

Golf A5 Wolfsburg, Assembly Part 2, Level of automation 2

Parameters:					
Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Lifting up and fitting complete powertrain, Underbody work	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,98 €	0,1365 €	0,0006 €	2.597.000 €	1,95 €	30	0,047 €	0,280 €	3	0,005 €	4,42 €
Fitting gear shift	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,20 €	0,0273 €	0,0006 €	523.000 €	0,39 €	8	0,013 €	0,056 €	0,5	0,001 €	1,61 €
Closing bonnet	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,02 €	0,0021 €	0,0006 €	40.000 €	0,03 €	1	0,002 €	0,004 €	0,5	0,001 €	0,96 €
Lifting down fitting unit	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,22 €	0,0308 €	0,0006 €	580.000 €	0,44 €	2	0,003 €	0,063 €	0	0,000 €	1,68 €
Fitting rear glass/windscreen 1	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0,286	0,20 €	0,073	0,09 €	0,25 €	0,0343 €	0,0008 €	647.000 €	0,49 €	15	0,024 €	0,070 €	1	0,002 €	2,05 €
Fitting rear glass/windscreen 2	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0,286	0,20 €	0,073	0,09 €	0,25 €	0,0343 €	0,0008 €	647.000 €	0,49 €	15	0,024 €	0,070 €	1	0,002 €	2,05 €
Fitting side glasses	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0,572	0,39 €	0,090	0,11 €	0,25 €	0,0343 €	0,0010 €	647.000 €	0,49 €	25	0,039 €	0,070 €	1	0,002 €	2,29 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Stamping VIN	2,3	1,76 €	0,14	0,11 €	0	0,00 €		0,00 €	0	0,00 €	0,142	0,17 €	0,24 €	0,0336 €	0,0015 €	636.000 €	0,48 €	5	0,008 €	0,064 €	3	0,005 €	3,13 €
Total:	2,300		0,140		2,500		4,282		1,143		0,606												
Total net costs per unit:		1,76 €		0,11 €		1,89 €		3,29 €		0,79 €		0,74 €	2,41 €	0,33 €	0,01 €								
Total gross costs per unit (+11%):		1,95 €		0,12 €		2,10 €		3,65 €		0,88 €		0,82 €	2,68 €	0,37 €	0,01 €		4,76 €		0,16 €	0,68 €		0,02 €	

Total costs per unit: 18,19 €

Golf A5 Wolfsburg, Assembly Part 2, Level of automation 3

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Lifting up and fitting complete powertrain, Underbody work	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,98 €	0,1365 €	0,0006 €	2.597.000 €	1,95 €	30	0,047 €	0,280 €	3	0,005 €	4,42 €
Lifting down fitting unit	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,22 €	0,0308 €	0,0006 €	580.000 €	0,44 €	2	0,003 €	0,063 €	0	0,000 €	1,68 €
Fitting rear glass/windscreen 1	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0,286	0,20 €	0,073	0,09 €	0,25 €	0,0343 €	0,0008 €	647.000 €	0,49 €	15	0,024 €	0,070 €	1	0,002 €	2,05 €
Fitting rear glass/windscreen 2	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0,286	0,20 €	0,073	0,09 €	0,25 €	0,0343 €	0,0008 €	647.000 €	0,49 €	15	0,024 €	0,070 €	1	0,002 €	2,05 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Stamping VIN	2,3	1,76 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,142	0,17 €	0,24 €	0,0336 €	0,0015 €	636.000 €	0,48 €	5	0,008 €	0,064 €	3	0,005 €	3,13 €
Fitting gear shift	1,2	0,92 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,078	0,09 €	0,01 €	0,0007 €	0,0008 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,27 €
Closing bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Fitting side glasses	1,252	0,96 €	0,55	0,42 €	0	0,00 €	0	0,00 €	0	0,00 €	0,105	0,12 €	0,11 €	0,0154 €	0,0011 €	297.000 €	0,22 €	10	0,016 €	0,030 €	1	0,002 €	2,07 €
Total:	4,752		0,830		1,429		2,447		0,572		0,585												
Total net costs per unit:		3,64 €		0,64 €		1,08 €		1,88 €		0,40 €		0,70 €	2,06 €	0,29 €	0,01 €								
Total gross costs per unit (+11%):		4,04 €		0,71 €		1,20 €		2,09 €		0,44 €		0,78 €	2,29 €	0,32 €	0,01 €		4,08 €		0,12 €	0,58 €		0,02 €	

Total costs per unit: 16,67 €

Golf A5 Wolfsburg, Assembly Part 2, Level of automation 4

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60 \min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60 \min/h}$	
Lifting up and fitting complete powertrain, Underbody work	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,98 €	0,1365 €	0,0006 €	2.597.000 €	1,95 €	30	0,047 €	0,280 €	3	0,005 €	4,42 €
Lifting down fitting unit	0	0,00 €	0	0,00 €	0,357	0,27 €	0,612	0,47 €	0	0,00 €	0,057	0,07 €	0,22 €	0,0308 €	0,0006 €	580.000 €	0,44 €	2	0,003 €	0,063 €	0	0,000 €	1,68 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60 \min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60 \min/h}$	
Stamping VIN	2,3	1,76 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,142	0,17 €	0,24 €	0,0336 €	0,0015 €	636.000 €	0,48 €	5	0,008 €	0,064 €	3	0,005 €	3,13 €
Fitting gear shift	1,2	0,92 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,078	0,09 €	0,01 €	0,0007 €	0,0008 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,27 €
Closing bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Fitting rear glass/windscreen 1	3,2	2,44 €	0,55	0,42 €	0	0,00 €	0	0,00 €	0	0,00 €	0,219	0,26 €	0,15 €	0,0210 €	0,0023 €	394.000 €	0,30 €	20	0,032 €	0,039 €	1	0,002 €	4,03 €
Fitting side glasses	1,252	0,96 €	0,55	0,42 €	0	0,00 €	0	0,00 €	0	0,00 €	0,105	0,12 €	0,11 €	0,0154 €	0,0011 €	297.000 €	0,22 €	10	0,016 €	0,030 €	1	0,002 €	2,07 €
Total:	7,952		1,380		0,714		1,224		0,000		0,658												
Total net costs per unit:		6,08 €		1,06 €		0,54 €		0,94 €		0,00 €		0,78 €	1,71 €	0,24 €	0,01 €								
Total gross costs per unit (+11%):		6,75 €		1,18 €		0,60 €		1,04 €		0,00 €		0,87 €	1,90 €	0,27 €	0,01 €		3,40 €		0,11 €	0,48 €		0,02 €	

Total costs per unit: 16,60 €

Golf A5 Wolfsburg, Assembly Part 2, Level of automation 5

Parameters:					
Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	
Stamping VIN	2,3	1,76 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,142	0,17 €	0,24 €	0,0336 €	0,0015 €	636.000 €	0,48 €	5	0,008 €	0,064 €	3	0,005 €	3,13 €
Fitting gear shift	1,2	0,92 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,078	0,09 €	0,01 €	0,0007 €	0,0008 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,27 €
Closing bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Fitting rear glass/windscreen 1	3,2	2,44 €	0,55	0,42 €	0	0,00 €	0	0,00 €	0	0,00 €	0,219	0,26 €	0,15 €	0,0210 €	0,0023 €	394.000 €	0,30 €	20	0,032 €	0,039 €	1	0,002 €	4,03 €
Fitting side glasses	1,252	0,96 €	0,55	0,42 €	0	0,00 €	0	0,00 €	0	0,00 €	0,105	0,12 €	0,11 €	0,0154 €	0,0011 €	297.000 €	0,22 €	10	0,016 €	0,030 €	1	0,002 €	2,07 €

Stations with parameters that are taken from Golf A5 SA:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_SA}}{n} + \frac{P_{Ej} \cdot C_{W\_SA} \cdot t_C}{60 min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_SA}} \cdot C_{EQ\_SA}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60 min/h}$	
Lifting up and fitting complete powertrain, Underbody work	45,34	34,64 €	0,83	0,63 €	0	0,00 €	0	0,00 €	0	0,00 €	2,693	3,16 €	0,23 €	0,0315 €	0,0288 €	605.000 €	0,45 €	10	0,016 €	0,163 €	3	0,005 €	43,61 €

Total:	53,292		2,210		0,000		0,000		0,000		3,237											
Total net costs per unit:		40,72 €		1,69 €		0,00 €		0,00 €		0,00 €		3,80 €	0,74 €	0,10 €	0,03 €							
Total gross costs per unit (+11%):		45,20 €		1,88 €		0,00 €		0,00 €		0,00 €		4,22 €	0,82 €	0,11 €	0,04 €		1,46 €		0,07 €	0,30 €		0,02 €

Total costs per unit: 54,11 €

Golf A5 Wolfsburg, Assembly Part 3, Level of automation 1

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60\ min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\ min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,01 €	0,0007 €	0,0003 €	17.600 €	0,01 €	8	0,013 €	0,002 €	0,5	0,001 €	0,50 €
Putting in/Fitting CW trim panel	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0,572	0,39 €	0,063	0,07 €	0,28 €	0,0385 €	0,0007 €	731.000 €	0,55 €	10	0,016 €	0,079 €	1	0,002 €	1,93 €
Putting in battery	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0,572	0,39 €	0,063	0,07 €	0,16 €	0,0224 €	0,0007 €	431.000 €	0,32 €	10	0,016 €	0,046 €	0,5	0,001 €	1,52 €
Fitting battery	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,08 €	0,0112 €	0,0003 €	210.000 €	0,16 €	8	0,013 €	0,023 €	1	0,002 €	0,77 €
Fitting cross member	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,14 €	0,0196 €	0,0003 €	373.000 €	0,28 €	15	0,024 €	0,040 €	1	0,002 €	0,99 €
Fitting rear bumper	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,28 €	0,0385 €	0,0003 €	733.000 €	0,55 €	10	0,016 €	0,079 €	0,5	0,001 €	1,47 €
Fitting frontend	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,29 €	0,0406 €	0,0003 €	777.000 €	0,58 €	30	0,047 €	0,084 €	1	0,002 €	1,55 €
Placing spare wheel in boot	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,09 €	0,0126 €	0,0003 €	242.000 €	0,18 €	10	0,016 €	0,026 €	0,5	0,001 €	0,80 €
Premounting/Fitting wheels	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,45 €	0,0623 €	0,0003 €	1.190.000 €	0,89 €	30	0,047 €	0,128 €	2	0,003 €	2,10 €
Total:	0		0		2,286		2,286		1,143		0,336												
Total net costs per unit:		0,00 €		0,00 €		1,71 €		1,71 €		0,78 €		0,42 €	1,78 €	0,25 €	0,00 €								
Total gross costs per unit (+11%):		0,00 €		0,00 €		1,90 €		1,90 €		0,87 €		0,47 €	1,98 €	0,28 €	0,00 €		3,52 €		0,21 €	0,51 €		0,02 €	

Total costs per unit: 11,63 €

Golf A5 Wolfsburg, Assembly Part 3, Level of automation 2

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Putting in battery	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0,572	0,39 €	0,063	0,07 €	0,16 €	0,0224 €	0,0007 €	431.000 €	0,32 €	10	0,016 €	0,046 €	0,5	0,001 €	1,52 €
Fitting battery	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,08 €	0,0112 €	0,0003 €	210.000 €	0,16 €	8	0,013 €	0,023 €	1	0,002 €	0,77 €
Fitting cross member	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,14 €	0,0196 €	0,0003 €	373.000 €	0,28 €	15	0,024 €	0,040 €	1	0,002 €	0,99 €
Fitting rear bumper	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,28 €	0,0385 €	0,0003 €	733.000 €	0,55 €	10	0,016 €	0,079 €	0,5	0,001 €	1,47 €
Fitting frontend	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,29 €	0,0406 €	0,0003 €	777.000 €	0,58 €	30	0,047 €	0,084 €	1	0,002 €	1,55 €
Placing spare wheel in boot	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,09 €	0,0126 €	0,0003 €	242.000 €	0,18 €	10	0,016 €	0,026 €	0,5	0,001 €	0,80 €
Premounting/Fitting wheels	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,45 €	0,0623 €	0,0003 €	1.190.000 €	0,89 €	30	0,047 €	0,128 €	2	0,003 €	2,10 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\ min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\ min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	2,29	1,75 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,142	0,17 €	0,01 €	0,0007 €	0,0015 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	2,28 €

Total:	2,290		0,140		1,778		1,778		0,572		0,385											
Total net costs per unit:		1,75 €		0,11 €		1,33 €		1,33 €		0,39 €		0,48 €	1,50 €	0,21 €	0,00 €							
Total gross costs per unit (+11%):		1,94 €		0,12 €		1,48 €		1,48 €		0,43 €		0,53 €	1,67 €	0,23 €	0,00 €		2,97 €		0,18 €	0,43 €		0,01 €

Total costs per unit: 11,48 €

Golf A5 Wolfsburg, Assembly Part 3, Level of automation 3

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60\ min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\ min/h}$	
Putting in battery	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0,572	0,39 €	0,063	0,07 €	0,16 €	0,0224 €	0,0007 €	431.000 €	0,32 €	10	0,016 €	0,046 €	0,5	0,001 €	1,52 €
Fitting battery	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,08 €	0,0112 €	0,0003 €	210.000 €	0,16 €	8	0,013 €	0,023 €	1	0,002 €	0,77 €
Fitting frontend	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,29 €	0,0406 €	0,0003 €	777.000 €	0,58 €	30	0,047 €	0,084 €	1	0,002 €	1,55 €
Placing spare wheel in boot	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,09 €	0,0126 €	0,0003 €	242.000 €	0,18 €	10	0,016 €	0,026 €	0,5	0,001 €	0,80 €
Premounting/Fitting wheels	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,45 €	0,0623 €	0,0003 €	1.190.000 €	0,89 €	30	0,047 €	0,128 €	2	0,003 €	2,10 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs: Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Operating material: Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Material: Operating supplies (c_{fix})		Total per station (gross)
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60\ min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\ min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	2,29	1,75 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,142	0,17 €	0,01 €	0,0007 €	0,0015 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	2,28 €
Fitting cross member	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,02 €	0,0021 €	0,0008 €	35.000 €	0,03 €	1	0,002 €	0,003 €	0,5	0,001 €	1,25 €
Fitting rear bumper	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,01 €	0,0007 €	0,0008 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,21 €
Total:	4,570		0,420		1,270		1,270		0,572		0,475												
Total net costs per unit:		3,49 €		0,33 €		0,95 €		0,95 €		0,39 €		0,58 €	1,11 €	0,15 €	0,01 €								
Total gross costs per unit (+11%):		3,87 €		0,37 €		1,05 €		1,05 €		0,43 €		0,64 €	1,23 €	0,17 €	0,01 €		2,18 €		0,15 €	0,31 €		0,01 €	

Total costs per unit: 11,48 €

Golf A5 Wolfsburg, Assembly Part 3, Level of automation 4

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_WOB}}{n}+\frac{P_{Ej}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_WOB}}\cdot C_{EQ\_WOB}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	
Fitting frontend	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,29 €	0,0406 €	0,0003 €	777.000 €	0,58 €	30	0,047 €	0,084 €	1	0,002 €	1,55 €
Placing spare wheel in boot	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,09 €	0,0126 €	0,0003 €	242.000 €	0,18 €	10	0,016 €	0,026 €	0,5	0,001 €	0,80 €
Premounting/Fitting wheels	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,45 €	0,0623 €	0,0003 €	1.190.000 €	0,89 €	30	0,047 €	0,128 €	2	0,003 €	2,10 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0{,}5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	2,29	1,75 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,142	0,17 €	0,01 €	0,0007 €	0,0015 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	2,28 €
Putting in/Fitting battery	1,14	0,87 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,083	0,10 €	0,04 €	0,0049 €	0,0009 €	90.700 €	0,07 €	5	0,008 €	0,009 €	1,5	0,002 €	1,45 €
Fitting cross member	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,02 €	0,0021 €	0,0008 €	35.000 €	0,03 €	1	0,002 €	0,003 €	0,5	0,001 €	1,25 €
Fitting rear bumper	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,01 €	0,0007 €	0,0008 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,21 €
Total:	5,710		0,700		0,763		0,763		0,000		0,465												
Total net costs per unit:		4,36 €		0,54 €		0,57 €		0,57 €		0,00 €		0,57 €	0,91 €	0,12 €	0,00 €								
Total gross costs per unit (+11%):		4,84 €		0,60 €		0,63 €		0,63 €		0,00 €		0,63 €	1,01 €	0,13 €	0,01 €		1,77 €		0,12 €	0,25 €		0,01 €	

Total costs per unit: 10,64 €

Golf A5 Wolfsburg, Assembly Part 3, Level of automation 5

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Golf A5 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_WOB}}{n} + \frac{P_{Ej} \cdot C_{W\_WOB} \cdot t_C}{60\,min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_WOB}} \cdot C_{EQ\_WOB}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\,min/h}$	
Fitting frontend	0	0,00 €	0	0,00 €	0,254	0,19 €	0,254	0,19 €	0	0,00 €	0,030	0,04 €	0,29 €	0,0406 €	0,0003 €	777.000 €	0,58 €	30	0,047 €	0,084 €	1	0,002 €	1,55 €

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0{,}5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60\,min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\,min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	2,29	1,75 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,142	0,17 €	0,01 €	0,0007 €	0,0015 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	2,28 €
Putting in/Fitting battery	1,14	0,87 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,083	0,10 €	0,04 €	0,0049 €	0,0009 €	90.700 €	0,07 €	5	0,008 €	0,009 €	1,5	0,002 €	1,45 €
Fitting cross member	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,02 €	0,0021 €	0,0008 €	35.000 €	0,03 €	1	0,002 €	0,003 €	0,5	0,001 €	1,25 €
Fitting rear bumper	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,01 €	0,0007 €	0,0008 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,21 €
Placing spare wheel in boot	0,728	0,56 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,051	0,06 €	0,03 €	0,0035 €	0,0005 €	70.000 €	0,05 €	5	0,008 €	0,007 €	0,5	0,001 €	0,91 €
Premounting/Fitting wheels	3,935	3,01 €	0,97	0,74 €	0	0,00 €	0	0,00 €	0	0,00 €	0,286	0,34 €	0,39 €	0,0539 €	0,0031 €	1.020.000 €	0,77 €	15	0,024 €	0,102 €	1,5	0,002 €	5,93 €
Total:	10,373		1,810		0,254		0,254		0,000		0,742												
Total net costs per unit:		7,93 €		1,39 €		0,19 €		0,19 €		0,00 €		0,89 €	0,79 €	0,11 €	0,01 €								
Total gross costs per unit (+11%):		8,80 €		1,54 €		0,21 €		0,21 €		0,00 €		0,99 €	0,88 €	0,12 €	0,01 €		1,52 €		0,09 €	0,21 €		0,01 €	

Total costs per unit: 14,58 €

Golf A5 Wolfsburg, Assembly Part 3, Level of automation 6

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs														
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}
	$c_{P\_...j} = \frac{t_{M\_...j} \cdot C_{P\_W}}{t_{SH} \cdot d_W}$								$c_{P\_Dj} = \frac{t_{M\_Dj} \cdot C_{P\_D}}{t_{SH} \cdot d_W}$		$c_{P\_Mj} = n_{Mj} \cdot C_{P\_M} \cdot \frac{t_C}{t_{SH} \cdot d_W}$		$c_{P\_MAj} = c_{INVj} \cdot 0,5$	$c_{P\_Pj} = c_{INVj} \cdot 0.07$	$c_{P\_IEj} = \frac{\sum t_{Mj}}{2} \cdot \frac{d_{WW} \cdot C_{P\_IE}}{d_W} \cdot \frac{1}{a \cdot n}$
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €
Putting in/Fitting CW trim panel	2,29	1,75 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,142	0,17 €	0,01 €	0,0007 €	0,0015 €
Putting in/Fitting battery	1,14	0,87 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,083	0,10 €	0,04 €	0,0049 €	0,0009 €
Fitting cross member	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,02 €	0,0021 €	0,0008 €
Fitting rear bumper	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,01 €	0,0007 €	0,0008 €
Fitting frontend	6,86	5,24 €	0,56	0,43 €	0	0,00 €	0	0,00 €	0	0,00 €	0,433	0,51 €	0,39 €	0,0546 €	0,0046 €
Placing spare wheel in boot	0,728	0,56 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,051	0,06 €	0,03 €	0,0035 €	0,0005 €
Premounting/Fitting wheels	3,935	3,01 €	0,97	0,74 €	0	0,00 €	0	0,00 €	0	0,00 €	0,286	0,34 €	0,39 €	0,0539 €	0,0031 €
Total:	17,233		2,370		0,000		0,000		0,000		1,145				
Total net costs per unit:		13,17 €		1,82 €		0,00 €		0,00 €		0,00 €		1,36 €	0,89 €	0,12 €	0,01 €
Total gross costs per unit (+11%):		14,62 €		2,02 €		0,00 €		0,00 €		0,00 €		1,51 €	0,99 €	0,13 €	0,01 €

Station	Operating material					Material		Total per station (gross)
	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
		$c_{INVj} = \frac{C_{INVj}}{a \cdot n}$		$c_{Ej} = \frac{P_{Ej} \cdot C_{POW\_Auto5000}}{n} + \frac{P_{Ej} \cdot C_{W\_Auto5000} \cdot t_C}{60\ min/h}$	$c_{EQj} = \frac{1}{n} \cdot \frac{C_{INVj}}{C_{INV\_Auto5000}} \cdot C_{EQ\_Auto5000}$		$c_{OSj} = \frac{P_{OSj} \cdot C_{POW\_WOB}}{n} + \frac{P_{OSj} \cdot C_{W\_WOB} \cdot t_C}{60\ min/h}$	
Opening bonnet	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	2,28 €
Putting in/Fitting battery	90.700 €	0,07 €	5	0,008 €	0,009 €	1,5	0,002 €	1,45 €
Fitting cross member	35.000 €	0,03 €	1	0,002 €	0,003 €	0,5	0,001 €	1,25 €
Fitting rear bumper	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,21 €
Fitting frontend	1.040.000 €	0,78 €	60	0,095 €	0,104 €	1,5	0,002 €	8,34 €
Placing spare wheel in boot	70.000 €	0,05 €	5	0,008 €	0,007 €	0,5	0,001 €	0,91 €
Premounting/Fitting wheels	1.020.000 €	0,77 €	15	0,024 €	0,102 €	1,5	0,002 €	5,93 €
Total gross costs per unit (+11%):		1,72 €		0,14 €	0,23 €		0,01 €	

Total costs per unit: 21,37 €

Golf A5 Wolfsburg, Assembly Part 3, Level of automation 7

Parameters:

Cycle time t_C	1,143	min/unit	number of units n	190341	unit/year
Shift time t_{SH}	392	min/shift			
Number of shifts n_S	3	shifts/day			
Working days d_W	185	days/year			
Personnel costs rate IE C_{P_IE}	77000	€/year			
Personnel costs rate master C_{P_M}	74500	€/year			
Personnel costs rate worker (operator, QCC, reworker) C_{P_W}	55400	€/year			
Personnel costs rate depositor C_{P_D}	50100	€/year			
Period of depreciation a	7	years			
Total investment costs C_{INV_WOB}	19002600	€			
Total equipment costs C_{EQ_WOB}	390000	€/year			
Total investment costs $C_{INV\_Auto5000}$	8933700	€			
Total equipment costs $C_{EQ\_Auto5000}$	170000	€/year			
Total investment costs C_{INV_SA}	2843000	€			
Total equipment costs C_{EQ_SA}	146000	€/year			
Energy costs rate C_{POW_WOB}	46	€/kW*year			
Energy costs rate C_{W_WOB}	0,070	€/kWh			

Stations with parameters that are taken from Auto5000 Wolfsburg:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_Auto5000}}{n}+\frac{P_{Ej}\cdot C_{W\_Auto5000}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_Auto5000}}\cdot C_{EQ\_Auto5000}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	
Opening bonnet	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0	0,00 €	0,000	0,00 €	0,00 €	0,0000 €	0,0000 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,00 €
Putting in/Fitting CW trim panel	2,29	1,75 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,142	0,17 €	0,01 €	0,0007 €	0,0015 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	2,28 €
Fitting cross member	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,02 €	0,0021 €	0,0008 €	35.000 €	0,03 €	1	0,002 €	0,003 €	0,5	0,001 €	1,25 €
Fitting rear bumper	1,14	0,87 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,075	0,09 €	0,01 €	0,0007 €	0,0008 €	11.000 €	0,01 €	1	0,002 €	0,001 €	0,5	0,001 €	1,21 €

Stations with parameters that are taken from Golf A5 SA:

Station	Personnel costs															Operating material					Material		Total per station (gross)
	Workers in the line (c_{var})		QCC-workers (c_{var})		Reworker (c_{var})		Other workers (c_{var})		Depositor (c_{var})		Master (c_{var})		Maintenance & technical service (c_{fix})	Planning (c_{fix})	Industrial engineering (c_{fix})	Capital investment (c_{fix})		Energy (c_{fix})		Equipment (c_{fix})	Operating supplies (c_{fix})		
	t_{M_DWj}	c_{P_DWj}	t_{M_QCCj}	c_{P_QCCj}	t_{M_RWj}	c_{P_RWj}	t_{M_OWj}	c_{P_OWj}	t_{M_Dj}	c_{P_Dj}	n_{Mj}	c_{P_Mj}	c_{P_MAj}	c_{P_Pj}	c_{P_IEj}	C_{INVj}	c_{INVj}	P_{Ej}	c_{Ej}	c_{EQj}	P_{OSj}	c_{OSj}	
	$c_{P\_...j}=\frac{t_{M\_...j}\cdot C_{P\_W}}{t_{SH}\cdot d_W}$								$c_{P\_Dj}=\frac{t_{M\_Dj}\cdot C_{P\_D}}{t_{SH}\cdot d_W}$		$c_{P\_Mj}=n_{Mj}\cdot C_{P\_M}\cdot\frac{t_C}{t_{SH}\cdot d_W}$		$c_{P\_MAj}=c_{INVj}\cdot 0,5$	$c_{P\_Pj}=c_{INVj}\cdot 0.07$	$c_{P\_IEj}=\frac{\sum t_{Mj}}{2}\cdot\frac{d_{WW}\cdot C_{P\_IE}}{d_W}\cdot\frac{1}{a\cdot n}$		$c_{INVj}=\frac{C_{INVj}}{a\cdot n}$		$c_{Ej}=\frac{P_{Ej}\cdot C_{POW\_SA}}{n}+\frac{P_{Ej}\cdot C_{W\_SA}\cdot t_C}{60\,min/h}$	$c_{EQj}=\frac{1}{n}\cdot\frac{C_{INVj}}{C_{INV\_SA}}\cdot C_{EQ\_SA}$		$c_{OSj}=\frac{P_{OSj}\cdot C_{POW\_WOB}}{n}+\frac{P_{OSj}\cdot C_{W\_WOB}\cdot t_C}{60\,min/h}$	
Putting in/Fitting battery	1,38	1,05 €	0,28	0,21 €	0	0,00 €	0	0,00 €	0	0,00 €	0,097	0,11 €	0,01 €	0,0014 €	0,0010 €	20.000 €	0,02 €	1	0,002 €	0,005 €	0,5	0,001 €	1,56 €
Fitting frontend	8,6	6,57 €	0,56	0,43 €	0	0,00 €	0	0,00 €	0	0,00 €	0,534	0,63 €	0,09 €	0,0119 €	0,0057 €	225.000 €	0,17 €	10	0,016 €	0,061 €	1	0,002 €	8,84 €
Placing spare wheel in boot	0,68	0,52 €	0,14	0,11 €	0	0,00 €	0	0,00 €	0	0,00 €	0,048	0,06 €	0,00 €	0,0000 €	0,0005 €	0 €	0,00 €	0	0,000 €	0,000 €	0	0,000 €	0,77 €
Premounting/Fitting wheels	6,64	5,07 €	0,97	0,74 €	0	0,00 €	0	0,00 €	0	0,00 €	0,444	0,52 €	0,21 €	0,0287 €	0,0048 €	550.000 €	0,41 €	5	0,008 €	0,148 €	1	0,002 €	7,86 €
Total:	21,870		2,370		0,000		0,000		0,000		1,415												
Total net costs per unit:		16,70 €		1,82 €		0,00 €		0,00 €		0,00 €		1,67 €	0,35 €	0,05 €	0,02 €								
Total gross costs per unit (+11%):		18,54 €		2,02 €		0,00 €		0,00 €		0,00 €		1,85 €	0,39 €	0,06 €	0,02 €		0,65 €		0,03 €	0,22 €		0,01 €	

Total costs per unit: 23,77 €

Appendix E

Tables Golf A5 Wolfsburg:

Calculation of total costs per unit

for each level of automation

Capital investment costs C_{INVj} of the three production sites

Station	Production site Golf A5 Wolfsburg	Production site Auto5000 GmbH Wolfsburg	Production site Golf A5 Uitenhage
Rollforming tailgate	396.000 €	34.000 €	34.000 €
Fitting cockpit location brackets	176.000 €	73.000 €	73.000 €
Rollforming doors	918.000 €	68.000 €	68.000 €
Cleaning window flange, Closing tailgate	891.000 €	0 €	0 €
Priming window flange, Opening bonnet	1.141.000 €	0 €	0 €
Applying cockpit glue	371.000 €	371.000 €	192.000 €
Cockpit fitting 1	1.586.000 €	805.500 €	
Cockpit fitting 2	1.586.000 €	805.500 €	0 €
Removing cable box, Remaining screw connections	176.000 €	0 €	0 €
Remaining screw connections	461.000 €	0 €	0 €
Stamping VIN	915.000 €	636.000 € [1]	317.000 €
Lifting up and fitting complete powertrain, Underbody work	2.597.000 €	2.597.000 €	605.000 €
Fitting gear shift	523.000 €	11.000 €	11.000 €
Closing bonnet	40.000 €	0 €	0 €
Lifting down fitting unit	580.000 €	580.000 €	0 €
Fitting rear glass/windscreen 1	647.000 €	394.000 €	394.000 €
Fitting rear glass/windscreen 2	647.000 €		
Fitting side glasses	647.000 €	297.000 €	297.000 €
Opening bonnet	17.600 €	0 €	0 €
Putting in/Fitting CW trim panel	731.000 €	11.000 €	11.000 €
Putting in battery	431.000 €	90.700 €	0 €
Fitting battery	210.000 €		20.000 €
Fitting cross member	373.000 €	35.000 €	35.000 €
Fitting rear bumper	733.000 €	11.000 €	11.000 €
Fitting frontend	777.000 €	1.040.000 €	225.000 €
Placing spare wheel in boot	242.000 €	70.000 €	0 €
Premounting/Fitting wheels	1.190.000 €	1.020.000 €	550.000 €
Total:	**19.002.600 €**	**8.933.700 €**	**2.843.000 €**

Source: Own presentation (Details from Volkswagen AG Wolfsburg and Uitenhage, Planning)

[1] This investment costs are multiplied by 3 to represent stamping of 3 VINs (in Auto5000, only 1 VIN is stamped)

Power P_{Ej} of the three production sites

Station	Production site		
	Golf A5 Wolfsburg	Auto5000 GmbH Wolfsburg	Golf A5 Uitenhage
Rollforming tailgate	10 kW	1 kW	1 kW
Fitting cockpit location brackets	20 kW	1 kW	1 kW
Rollforming doors	40 kW	1 kW	1 kW
Cleaning window flange, Closing tailgate	30 kW	0 kW	0 kW
Priming window flange, Opening bonnet	30 kW	0 kW	0 kW
Applying cockpit glue	10 kW	10 kW	10 kW
Cockpit fitting 1	60 kW	65 kW	
Cockpit fitting 2	60 kW	65 kW	0 kW
Removing cable box, Remaining screw connections	1 kW	1 kW	1 kW
Remaining screw connections	10 kW	1 kW	0,0
Stamping VIN	15 kW	5 kW	5 kW
Lifting up and fitting complete powertrain, Underbody work	30 kW	30 kW	10 kW
Fitting gear shift	8 kW	1 kW	1 kW
Closing bonnet	1 kW	0 kW	0 kW
Lifting down fitting unit	2 kW	2 kW	0 kW
Fitting rear glass/windscreen 1	15 kW	20 kW	20 kW
Fitting rear glass/windscreen 2	15 kW		
Fitting side glasses	25 kW	10 kW	10 kW
Opening bonnet	8 kW	0 kW	0 kW
Putting in/Fitting CW trim panel	10 kW	1 kW	1 kW
Putting in battery	10 kW	5 kW	0 kW
Fitting battery	8 kW		1 kW
Fitting cross member	15 kW	1 kW	1 kW
Fitting rear bumper	10 kW	1 kW	1 kW
Fitting frontend	30 kW	60 kW	10 kW
Placing spare wheel in boot	10 kW	5 kW	0 kW
Premounting/Fitting wheels	30 kW	15 kW	5 kW

Source: Own presentation (estimated according to energy audit in Golf A5 assembly line in Wolfsburg, department Maintenance)[2]

[2] In the energy audit of Golf A5 Wolfsburg, the power of each Mechanisation is given. The power of each Mechanisation is broken down to each station of the certain Assembly Part depending on the circumference of the operating material in the certain station. The powers for both of the other production sites are estimated on the basis of the powers of Golf A5 Wolfsburg

Power P_{OSj} of the three production sites

Station	Production site		
	Golf A5 Wolfsburg	Auto5000 GmbH Wolfsburg	Golf A5 Uitenhage
Rollforming tailgate	0,5 kW	0,5 kW	0,5 kW
Fitting cockpit location brackets	1,5 kW	0,5 kW	0,5 kW
Rollforming doors	1,0 kW	1,0 kW	1,0 kW
Cleaning window flange, Closing tailgate	1,0 kW	0,0 kW	0,0 kW
Priming window flange, Opening bonnet	1,0 kW	0,0 kW	0,0 kW
Applying cockpit glue	1,5 kW	1,5 kW	3,0 kW
Cockpit fitting 1	4,5 kW	5,0 kW	
Cockpit fitting 2	4,5 kW	5,0 kW	0,0 kW
Removing cable box, Remaining screw connections	1,0 kW	0,0 kW	0,0 kW
Remaining screw connections	1,0 kW	1,0 kW	1,0 kW
Stamping VIN	0,5 kW	3,0 kW	3,0 kW
Lifting up and fitting complete powertrain, Underbody work	3,0 kW	3,0 kW	3,0 kW
Fitting gear shift	0,5 kW	0,5 kW	0,5 kW
Closing bonnet	0,5 kW	0,0 kW	0,0 kW
Lifting down fitting unit	0,0 kW	0,0 kW	0,0 kW
Fitting rear glass/windscreen 1	1,0 kW	1,0 kW	1,5 kW
Fitting rear glass/windscreen 2	1,0 kW		
Fitting side glasses	1,0 kW	1,0 kW	1,0 kW
Opening bonnet	0,5 kW	0,0 kW	0,0 kW
Putting in/Fitting CW trim panel	1,0 kW	0,5 kW	0,5 kW
Putting in battery	0,5 kW	1,5 kW	0,0 kW
Fitting battery	1,0 kW		0,5 kW
Fitting cross member	1,0 kW	0,5 kW	0,5 kW
Fitting rear bumper	0,5 kW	0,5 kW	0,5 kW
Fitting frontend	1,0 kW	1,5 kW	1,0 kW
Placing spare wheel in boot	0,5 kW	0,5 kW	0,0 kW
Premounting/Fitting wheels	2,0 kW	1,5 kW	1,0 kW

Source: Own presentation[3]

[3] In the energy audit of Golf A5 Wolfsburg, the powers of the Mechanisations are given. The powers are broken down to each station depending on the circumference of the operating material in the certain station. The powers for both of the other production sites are given for the whole assembly and also broken down to each station.

Appendix D

Capital investment costs C_{INVj}, power P_{Ej} and power P_{OSj}:

Necessary parameters for the cost calculation

Description of times in matrixes

First, the calculation of manufacturing times for reworking, or rather for other workers, should be described. Bases are the manufacturing times of the first level of automation for reworking, or rather other workers. These manufacturing times are broken down to the other levels of automation depending on the number of automated stations of a certain level in relation to the number of automated stations of the first level. With it, blank fields are not considered.

Next, the calculation of QCC workers should be described. The basis for their manufacturing times of each station is the Auto5000 GmbH with a cycle time of 1,38 min where these workers are used in practise. The examined stations are spread over several Manufacturing Parts, which are called FA.[1] For each Manufacturing Part a certain number of QCC workers is designated. As the examined stations are not in the same order as in the assembly of the Golf A5 in Wolfsburg, or rather in the analysis of this diploma thesis, the examined stations take only a certain part of all stations that are in a certain Manufacturing Part (FA). The relationship between each examined and non-examined area is estimated by the writer. The number of QCC workers that is used in practise, is multiplied by the estimated relationship. This relationship is distributed to the examined stations that are in the certain Manufacturing Part. In this way, each station receives a certain relationship. By multiplying this relationship by the cycle time of 1,38 min, the manufacturing time for a QCC worker of the certain station is calculated. The following shows the different Manufacturing Parts and the calculation of the manufacturing times t_{QCC} for QCC workers:

Manufacturing Part FA 7.1 Total number of QCC workers: 2 Examined stations:	Relation of examined area: 4/5 of whole FA 7.1 $\rightarrow 4/5 \cdot 2 = 8/5 = 16/10$	
Rollforming tailgate (Assembly Part 1)	$\rightarrow$ 2/10	$\rightarrow t_{QCC} = 2/10 \cdot 1{,}38$ min $= 0{,}28$ min
Rollforming doors (Assembly Part 1)	$\rightarrow$ 2/10	$\rightarrow t_{QCC} = 2/10 \cdot 1{,}38$ min $= 0{,}28$ min
Priming window flanges (Assembly Part 1)	$\rightarrow$ 1/10	$\rightarrow t_{QCC} = 1/10 \cdot 1{,}38$ min $= 0{,}14$ min
Fitting the cockpit 1 (Assembly Part 1)	$\rightarrow$ 3/10	$\rightarrow t_{QCC} = 3/10 \cdot 1{,}38$ min $= 0{,}41$ min
Fitting the cockpit 2 (Assembly Part 1)	$\rightarrow$ 3/10	$\rightarrow t_{QCC} = 3/10 \cdot 1{,}38$ min $= 0{,}41$ min
Stamping VINs (Assembly Part 2)	$\rightarrow$ 1/10	$\rightarrow t_{QCC} = 1/10 \cdot 1{,}38$ min $= 0{,}14$ min
Fitting side glasses (Assembly Part 2)	$\rightarrow$ 4/10	$\rightarrow t_{QCC} = 4/10 \cdot 1{,}38$ min $= 0{,}55$ min

Manufacturing Part FA 7.2 Total number of QCC workers: 2 Examined stations:	Relation of examined area: 1/5 of whole FA 7.2 $\rightarrow 1/5 \cdot 2 = 2/5$	
Fitting windscreen/rear glass (Assembly Part 2)	$\rightarrow$ 2/5	$\rightarrow t_{QCC} = 2/5 \cdot 1{,}38$ min $= 0{,}55$ min

[1] FA = Fertigungsabschnitt

Manufacturing Part FA 7.3 Total number of QCC workers: 1 <u>Examined stations:</u>	Relation of examined area: 4/5 of whole FA 7.3 → 4/5 · 1 = 4/5 = 8/10	
Lifting up/fitting complete powertrain, Underbodywork (Assembly Part 2)	→ 6/10	→ t_{QCC} = 6/10 · 1,38 min = 0,83 min
Fitting CW-trim panel (Assembly Part 3)	→ 1/10	→ t_{QCC} = 1/10 · 1,38 min = 0,14 min
Fitting cross member (Assembly Part 3)	→ 1/10	→ t_{QCC} = 1/10 · 1,38 min = 0,14 min

Manufacturing Part FA 9.1 Total number of QCC workers: 2 <u>Examined stations:</u>	Relation of examined area: 2/5 of whole FA 9.1 → 2/5 · 2 = 4/5 = 8/10	
Putting in/Fitting battery (Assembly Part 3)	→ 2/10	→ t_{QCC} = 2/10 · 1,38 min = 0,28 min
Fitting frontend/front bumper (Assembly Part 3)	→ 4/10	→ t_{QCC} = 4/10 · 1,38 min = 0,55 min (divided into 2 stations, each 0,28 min)
Fitting rear bumper (Assembly Part 3)	→ 1/10	→ t_{QCC} = 1/10 · 1,38 min = 0,14 min
Fitting gear shift (Assembly Part 2)	→ 1/10	→ t_{QCC} = 1/10 · 1,38 min = 0,14 min

Manufacturing Part FA 9.3 Total number of QCC workers: 2 <u>Examined stations:</u>	Relation of examined area: 2/5 of whole FA 9.3 → 2/5 · 2 = 4/5 = 8/10	
Placing spare wheel in boot (Assembly Part 3)	→ 1/10	→ t_{QCC} = 1/10 · 1,38 min = 0,14 min
Premounting/Fitting wheels (Assembly Part 3)	→ 7/10	→ t_{QCC} = 7/10 · 1,38 min = 0,97 min

Besides these calculated manufacturing times for a QCC worker t_{QCC} some additional assumptions are necessary:

Fitting cockpit location brackets (Assembly Part 1) (this operation is not done in Auto5000 GmbH)	→ +1/10	→ t_{QCC} = 1/10 · 1,38 min = 0,14 min
Manually applying cockpit glue in Golf A5 Uitenhage (Assembly Part 1)	→ +1/10	→ t_{QCC} = 1/10 · 1,38 min = 0,14 min
Cleaning window flange (Assembly Part 1) (this operation is not done in Auto5000 GmbH)	→ +1/10	→ t_{QCC} = 1/10 · 1,38 min = 0,14 min

At this place, all manufacturing times of QCC workers t_{QCC} are determined. Furthermore, each of the three matrixes has several remarks which are explained in the following paragraphs. The following remarks have been mentioned in the matrix of Assembly Part 1:

[1], [9] The manufacturing time is taken from the working schedule of Golf A4 (Details from Volkswagen AG Wolfsburg, department PWACI-B); the time is relevant for each level of this station

[2], [4], [6], [8], [10], [12], [14] See certain calculations of QCC workers above

[3], [15] The manufacturing time is taken from the production process plan of Golf A5 (Details from Volkswagen AG Wolfsburg, department PWACI-P); the time is relevant for each level of this station

[5] The manufacturing time is taken from assembly planning of Golf A4 (Details from Volkswagen AG Wolfsburg, department PWP-M/1); the time is relevant for each level of this station

[7] The manufacturing time is taken from the station "Priming window flange, Opening bonnet" because these stations are very similar and have same operations; relevant for each level of automation
Description: In practise, the window flanges are not cleaned additionally in the Golf A4 and Auto5000 GmbH assembly lines. The cleaning is not necessary for correct fitting of glasses. Therefore, no manufacturing times are available. To ensure comparable levels of automation, the cleaning is assumed in all levels of automation

[11] The manufacturing time is taken from the working schedule of Golf A4 (Details from Volkswagen AG Wolfsburg, department PWACI-B)
Description: The total manufacturing time for fitting the cockpit takes 7,8125 min. The cockpit fitment is a double cycle, which means that in 2 parallel stations the cockpit is fitted. It makes a double cycle time for the certain operation available. For calculating the number of workers, either the total manufacturing time has to be divided by the cycle time (many workers in 1 station), or the total manufacturing time has to be divided by the double cycle time to get the number of workers in each of the 2 stations (less workers in 2 stations):

1 station (normal cycle):

$$n_{W\_NS} = \frac{t_M}{t_C} \quad [\ldots]$$

n_{W_NS} = number of workers for the certain station […]
t_{Mj} = manufacturing time of station j [min/unit]
t_C = cycle time [min/unit]

2 stations (double cycle):

$$n_{W\_DS} = \frac{t_M}{2 \cdot t_C} = \frac{0,5 \cdot t_M}{t_C} \qquad [\ldots]$$

n_{W_DS} = number of workers for each of the 2 certain stations […]
t_{Mj} = manufacturing time of station j [min/unit]
t_C = cycle time [min/unit]

[13] The manufacturing time is taken from the working schedule of Golf A5 (Details from Volkswagen AG Uitenhage, department industrial engineering)
Description: As the manipulator is different from the manipulator in Auto5000 (no sensors), the manufacturing time from Uitenhage is used. In Uitenhage, there is no double cycle

[16] The manufacturing time for the QCC worker is a third of the QCC time of level 4

[17] The manufacturing time is taken from the production process plan of Golf A5 (Details from Volkswagen AG Wolfsburg, department PWACI-P)
Description: 1,143 min correspondent to 100% or rather 9 white fields. Therefore, each white field take a time of 1/9 · 1,143 min. The reworking times for the other levels of automation can be calculated by multiplying this

time with the number of white fields of each level of automation. All levels with no white fields have a reworking time of 0 min

[18] The manufacturing time is taken from the production process plan of Golf A5 (Details from Volkswagen AG Wolfsburg, department PWACI-P)
Description: Other workers are operators of machines, deputies of masters and team coordinators. 6,732 min correspondent to 100% or rather 9 white fields. The calculation of the times for the other levels is identical to [17]. All levels with no white fields have no other workers

The following remarks have been mentioned in the matrix of Assembly Part 2:

[1] The manufacturing time is taken from the working schedule of Golf A5 (Details from Volkswagen AG Uitenhage, department industrial engineering); the time is relevant for each level of this station
Description: The manufacturing time of Golf A5 Uitenhage is taken because there is no comparable manufacturing time of the Golf A4 assembly line

[2], [4], [6], [8], [10] See certain calculations of QCC workers above

[3] The manufacturing time is taken from the working schedule of Golf A5 (Details from Volkswagen AG Uitenhage, department industrial engineering)

[5] The manufacturing time is taken from an analysis about the Golf A5 (Details from Volkswagen AG Wolfsburg, department PWP-AM); the time is relevant for each level of this station

[7], [9] The manufacturing time is taken from the working schedule of Golf A4 (Details from Volkswagen AG Wolfsburg, department PWACI-B); the time is relevant for each level of this station

[11] The manufacturing time is taken from the production process plan of Golf A5 (Details from Volkswagen AG Wolfsburg, department PWACI-P)
Description: 2,857 min correspondent to 100% or rather 8 white fields. The calculation of the times for the other levels is identical to [17] of Assembly Part 1. All levels with no white fields have a reworking time of 0 min

[12] The manufacturing time is taken from the production process plan of Golf A5 (Details from Volkswagen AG Wolfsburg, department PWACI-P)
Description: 4,894 min correspondent to 100% or rather 8 white fields. The calculation of the times for the other levels is identical to [17] of Assembly Part 1. All levels with no white fields have no other workers

[13] The manufacturing time is taken from the production process plan of Golf A5 (Details from Volkswagen AG Wolfsburg, department PWACI-P)
Description: 0,572 min are needed for the windscreen and the rear glass and 0,572 min are needed for the side glasses. As soon as an operation is done manually, no depositor is needed anymore. In all manual stations the depositing of the glasses into the facilities is included in the certain manufacturing time

The following remarks have been mentioned in the matrix of Assembly Part 3:

[1], [3], [6], [8], The manufacturing time is taken from an analysis about the Golf A5 (Details from Volkswagen AG Wolfsburg, analysis VW 350 GP (reference Golf A4), department PWACI-P); the time is relevant for each level of this station

[2], [4], [7], [9], [11], [14], [17], [20]	See certain calculations of QCC workers above
[5]	The manufacturing time is taken from the working schedule of Golf A5 (Details from Volkswagen AG Uitenhage, department industrial engineering)
[10], [13]	The manufacturing time is taken from an analysis about the Golf A5 (Details from Volkswagen AG Wolfsburg, analysis VW 350 GP (reference Golf A4), department PWACI-P)
[12], [15], [18]	The manufacturing time is taken from the working schedule of Golf A5 (Details from Volkswagen AG Uitenhage, department industrial engineering) Description: The manufacturing time of Golf A5 Uitenhage is taken because there is no comparable manufacturing time of the Golf A4 assembly line
[16], [19]	The manufacturing time is taken from the working schedule of Golf A4 (Details from Volkswagen AG Wolfsburg, department PWACI-B); the time is relevant for level 5 and level 6

Matrix of Assembly Part 1

Manufacturing stations / Level of automation	A: Rollforming tailgate	B: Fitting cockpit location brackets	C: Rollforming doors	D: Cleaning window flange, Closing tailgate	E: Priming window flange, Opening bonnet	F: Applying cockpit glue	G: Cockpit fitting 1	H: Removing cable box, Remaining screw connections	I: Remaining screw connections	J: Cockpit fitting 2	K: Removing cable box, Remaining screw connections	L: Remaining screw connections	M: Manufacturing time t_M (Workers in the line) (All manual stations are considered)	N: QCC workers t_{QCC} (All manual stations are considered)	O: Reworking (All automated stations are considered)	P: Other workers (All automated stations are considered)	Q: Total manufacturing time
Level of automation 1 (Golf A5 WOB)	automatic (1 robot)	automatic (2 facilities)	automatic (4 robots)	automatic (3 robots)	automatic (3 robots)	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver t_M: 2,325 min[15]) t_{QCC}: 0,14 min[16]	automatic (1 robot)	2,325 min	0,14 min	1,143 min[17]	6,732 min[18]	10,34 min
Level of automation 2	manual (handrollforming device t_M: 1,07 min[1]) t_{QCC}: 0,28 min[2]	automatic (2 facilities)	manual (handrollforming device t_M: 2,4 min[5]) t_{QCC}: 0,28 min[6]	automatic (3 robots)	automatic (3 robots)	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver t_M: 2,325 min) t_{QCC}: 0,14 min	automatic (1 robot)	5,795 min	0,7 min	0,889 min	5,236 min	12,62 min
Level of automation 3	manual (handrollforming device t_M: 1,07 min) t_{QCC}: 0,28 min	automatic (2 facilities)	manual (handrollforming device t_M: 2,4 min) t_{QCC}: 0,28 min	manual (t_M: 2,81 min[7]) t_{QCC}: 0,14 min[8]	manual (t_M: 2,81 min[9]) t_{QCC}: 0,14 min[10]	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver t_M: 2,325 min) t_{QCC}: 0,14 min	automatic (1 robot)	11,415 min	0,98 min	0,635 min	3,74 min	16,77 min
Level of automation 4 (Auto5000 WOB)	manual (handrollforming device t_M: 1,07 min) t_{QCC}: 0,28 min	manual (electrical screwdriver and jigs t_M: 2,55 min) t_{QCC}: 0,14 min	manual (handrollforming device t_M: 2,4 min) t_{QCC}: 0,28 min	manual (t_M: 2,81 min) t_{QCC}: 0,14 min	manual (t_M: 2,81 min) t_{QCC}: 0,14 min	automatic (1 robot)	manual (manipulator with sensors and electrical screwdriver t_M: 3,906 min[11]) t_{QCC}: 0,41 min[12]			manual (manipulator and electrical screwdriver t_M: 3,906 min) t_{QCC}: 0,41 min			19,452 min	1,8 min	0,127 min	0,748 min	22,147 min
Level of automation 5 (Golf A5 SA)	manual (handrollforming device t_M: 1,07 min) t_{QCC}: 0,28 min	manual (electrical screwdriver and jigs t_M: 2,55 min) t_{QCC}: 0,14 min	manual (handrollforming device t_M: 2,4 min) t_{QCC}: 0,28 min	manual (t_M: 2,81 min) t_{QCC}: 0,14 min	manual (t_M: 2,81 min) t_{QCC}: 0,14 min	manual (manipulator without sensors , electrical screwdriver and 1 system t_M: 14,9 min[13]) t_{QCC}: 0,55 min[14]							26,54 min	1,53 min	0 min	0 min	28,08 min

Matrix of Assembly Part 2

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Manufacturing stations / Level of automation	Stamping Vehicle Identification Number (VIN) (3 times)	Lifting up and fitting complete powertrain, Underbody work and torque all bolts	Fitting gear shift	Closing bonnet	Lifting down	Fitting windscreen 1, Fitting rear glass 1	Fitting windscreen 2, Fitting rear glass 2	Fitting side glasses	Manufacturing time t_M (Workers in the line) (All manual stations are considered)	QCC workers t_{QCC} (All manual stations are considered)	Reworking (All automated stations are considered)	Other workers (All automated stations are considered)	Depositor	Total manufacturing time
Level of automation 1 (Golf A5 WOB)	automatic (2 robots and 1 facility)	automatic (18 facilities, 1 robot and 1 lifter)	automatic (1 robot)	automatic (1 robot)	automatic (3 facilities and 1 lifter)	automatic (2 robots) depositor	automatic (2 robots) depositor	automatic (4 robots) depositor	0 min	0 min	2,857 min[11]	4,894 min[12]	1,143 min[13]	8,894 min
Level of automation 2	manual (3 manipulators t_M: 2,3 min[1]) t_{QCC}: 0,14 min[2]	automatic (18 facilities, 1 robot and 1 lifter)	automatic (1 robot)	automatic (1 robot)	automatic (3 facilities and 1lifter)	automatic (2 robots) depositor	automatic (2 robots) depositor	automatic (4 robots) depositor	2,3 min	0,14 min	2,50 min	4,282 min	1,143 min	10,365 min
Level of automation 3	manual (3 manipulators t_M: 2,3 min) t_{QCC}: 0,14 min	automatic (18 facilities, 1 robot and 1 lifter)	manual (accu screwdriver t_M: 1,2 min[5]) t_{QCC}: 0,14 min[6]	manual	automatic (3 facilities and 1 lifter)	automatic (2 robots) depositor	automatic (2 robots) depositor	manual (t_M: 1,252 min[9] + 1 robot) t_{QCC}: 0,55 min[10]	4,752 min	0,83 min	1,429 min	2,447 min	0,572 min	10,04 min
Level of automation 4 (Auto5000 WOB)	manual (3 manipulators t_M: 2,3 min) t_{QCC}: 0,14 min	automatic (18 facilities, 1 robot and 1 lifter)	manual (accu screwdriver t_M: 1,2 min) t_{QCC}: 0,14 min	manual	automatic (3 facilities and 1 lifter)	manual (t_M: 3,2 min[7] + 2 robots) t_{QCC}: 0,55 min[8]		manual (t_M: 1,252 min + 1 robot) t_{QCC}: 0,55 min	7,952 min	1,38 min	0,714 min	1,224 min	0 min	11,29 min
Level of automation 5 (Golf A5 SA)	manual (3 manipulators t_M: 2,3 min) t_{QCC}: 0,14 min	manual (3 facilities and 1 lifter t_M: 45,34 min[3]) t_{QCC}: 0,83 min[4]	manual (accu screwdriver t_M: 1,2 min) t_{QCC}: 0,14 min	manual		manual (t_M: 3,2 min + 2 robots) t_{QCC}: 0,55 min		manual (t_M: 1,252 min + 1 robot) t_{QCC}: 0,55 min	53,292 min	2,21 min	0 min	0 min	0 min	55,532 min

Matrix of Assembly Part 3

	A	B	C	D	E	F	G	H	I	J	L	M	K	N	O	P
Manufacturing stations / Level of automation	Opening bonnet	Putting in/Fitting the CW-trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels	Manufacturing time t_M (Workers in the line) (All manual stations are considered)	QCC workers t_{QCC} (All automated stations are considered)	Reworking (All automated stations are considered)	Other workers (All automated stations are considered)	Depositor	Total Manufacturing time
Level of automation 1 (Golf A5 WOB)	automatic (1 facility)	automatic (2 facilities) depositor	automatic (1 robot and 0,5 manipulator) depositor	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)	0 min	0 min	2,286 min[22]	2,286 min[23]	1,143 min[24]	5,715 min
Level of automation 2	manual	manual (accu screwdriver t_M: 2,29 min[1]) t_{QCC}: 0,14 min[2]	automatic (1 robot and 0,5 manipulator) depositor	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)	2,29 min	0,14 min	1,778 min	1,778 min	0,572 min	6,558 min
Level of automation 3	manual	manual (accu screwdriver t_M: 2,29 min) t_{QCC}: 0,14 min	automatic (1 robot and 0,5 manipulator) depositor	automatic (1 robot)	manual (electrical screwdriver t_M: 1,14 min[6]) t_{QCC}: 0,14 min[7]	manual (accu screwdriver t_M: 1,14 min[8]) t_{QCC}: 0,14 min[9]	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)	4,57 min	0,42 min	1,27 min	1,27 min	0,572 min	8,102 min
Level of automation 4	manual	manual (accu screwdriver t_M: 2,29 min) t_{QCC}: 0,14 min	manual (manipulator and accu screwdriver t_M: 1,14 min[3]) t_{QCC}: 0,28 min[4]		manual (electrical screwdriver t_M: 1,14 min) t_{QCC}: 0,14 min	manual (accu screwdriver t_M: 1,14 min) t_{QCC}: 0,14 min	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)	5,71 min	0,7 min	0,763 min	0,763 min	0 min	7,936 min
Level of automation 5	manual	manual (accu screwdriver t_M: 2,29 min) t_{QCC}: 0,14 min	manual (manipulator and accu screwdriver t_M: 1,14 min) t_{QCC}: 0,28 min		manual (electrical screwdriver t_M: 1,14 min) t_{QCC}: 0,14 min	manual (accu screwdriver t_M: 1,14 min) t_{QCC}: 0,14 min	automatic (1 robot and 1 facility)		manual (manipulator t_M: 0,728 min[16]) t_{QCC}: 0,14 min[17]	manual (2 supporters, accu screwdriver and 2 manipulator t_M: 3,935 min[19]) t_{QCC}: 0,97 min[20]	10,373 min	1,81 min	0,254 min	0,254 min	0 min	12,701 min
Level of automation 6 (Auto5000 WOB)	manual	manual (accu screwdriver t_M: 2,29 min) t_{QCC}: 0,14 min	manual (accu screwdriver t_M: 1,14 min) t_{QCC}: 0,28 min		manual (electrical screwdriver t_M: 1,14 min) t_{QCC}: 0,14 min	manual (accu screwdriver t_M: 1,14 min) t_{QCC}: 0,14 min	manual (manipulator with sensors t_M: 3,43 min[10]) t_{QCC}: 0,28 min[11]	manual (accu screwdriver t_M: 3,43 min[13]) t_{QCC}: 0,28 min[14]	manual (manipulator t_M: 0,728 min) t_{QCC}: 0,14 min	manual (2 supporters, accu screwdriver and 2 manipulator t_M: 3,935 min) t_{QCC}: 0,97 min	17,233 min	2,37 min	0 min	0 min	0 min	19,613 min
Level of automation 7 (Golf A5 SA)	manual	manual (accu screwdriver t_M: 2,29 min) t_{QCC}: 0,14 min	manual (accu screwdriver t_M: 1,38 min[5]) t_{QCC}: 0,28 min		manual (electrical screwdriver t_M: 1,14 min) t_{QCC}: 0,14 min	manual (accu screwdriver t_M: 1,14 min) t_{QCC}: 0,14 min	manual (manipulator without sensors t_M: 3,87 min[12]) t_{QCC}: 0,28 min	manual (accu screwdriver t_M: 4,73 min[15]) t_{QCC}: 0,28 min	manual (t_M: 0,68 min[18]) t_{QCC}: 0,14 min	manual (electrical screwdriver t_M: 6,64 min[21]) t_{QCC}: 0,97 min	21,87 min	2,37 min	0 min	0 min	0 min	24,25 min

Appendix C

Matrixes (including description of times):

Created levels of automation

Morphological box for Assembly Part 1

Manufacturing stations	Assembly possibilities		
	1	2	3
Rollforming tailgate	**automatic** (1 robot) Golf A5 Wolfsburg	**manual** (handrollforming device) Touran Wolfsburg/ Golf A5 Uitenhage	
Fitting cockpit location brackets	**automatic** (2 facilities) Golf A5 Wolfsburg	**manual** Golf A5 Uitenhage	
Rollforming doors	**automatic** (4 robots) Golf A5 Wolfsburg	**manual** (handrollforming device) Touran Wolfsburg/ Golf A5 Uitenhage	
Cleaning window flange, Closing tailgate	**automatic** (3 robots) Golf A5 Wolfsburg	**manual**	
Applying cockpit glue	**automatic** (1 robot) Golf A5 Wolfsburg/ Touran Wolfsburg	**manual** (1 system) Golf A5 Uitenhage	
Cockpit fitting	**automatic** (2 facilities) Golf A5 Wolfsburg	**manual** (manipulator with sensors and electrical screwdriver) Touran Wolfsburg	**manual** (manipulator without sensors and electrical screwdriver) Golf A5 Uitenhage

Morphological box for Assembly Part 2

Manufacturing stations	Assembly possibilities	
	1	2
Stamping Vehicle Identification Number (VIN) (3 times)	**automatic** (2 robots and 1 facility) Golf A5 Wolfsburg	**manual** (3 manipulators) Golf A5 Uitenhage
Lifting up and fitting complete powertrain, Underbody work and screwing all bolts,	**automatic** (21 facilities, 1 robot and 2 lifter) Golf A5 Wolfsburg	**manual** (3 facilities and 1 lifter) Golf A5 Uitenhage
Fitting gear shift	**automatic** (1 robot) Golf A5 Wolfsburg	**manual** (accu screwdriver) Touran Wolfsburg/ Golf A5 Uitenhage
Closing bonnet	**automatic** (1 robot) Golf A5 Wolfsburg	**manual**
Fitting windscreen, Fitting rear glass	**automatic** (2 robots) Golf A5 Wolfsburg	**manual** (2 robots) Touran Wolfsburg/ Golf A5 Uitenhage
Fitting side glasses	**automatic** (4 robots) Golf A5 Wolfsburg	**manual** (1 robot) Touran Wolfsburg/ Golf A5 Uitenhage

Morphological box for Assembly Part 3

Manufacturing stations	Assembly possibilities		
	1	2	3
Opening bonnet	**automatic** (1 facility) Golf A5 Wolfsburg	**manual**	
Putting in/Fitting the CW trim panel	**automatic** (2 facilities) Golf A5 Wolfsburg	**manual** (accu screwdriver) Touran Wolfsburg/ Golf A5 Uitenhage	
Putting in battery	**automatic** (1 robot and 0,5 manipulator) Golf A5 Wolfsburg	**manual** (manipulator) Touran Wolfsburg	**manual** Golf A5 Uitenhage
Fitting battery	**automatic** (1 robot) Golf A5 Wolfsburg	**manual** (accu screwdriver) Touran Wolfsburg/ Golf A5 Uitenhage	
Fitting cross member	**automatic** (2 robots and 1 facility) Golf A5 Wolfsburg	**manual** (electrical screwdriver) Touran Wolfsburg/ Golf A5 Uitenhage	
Fitting rear bumper	**automatic** (1 robot and 1 facility) Golf A5 Wolfsburg	**manual** (accu screwdriver) Touran Wolfsburg/ Golf A5 Uitenhage	
Fitting frontend, fitting front bumper	**automatic** (1 robot and 1 facility) Golf A5 Wolfsburg	**manual** (manipulator with sensors and accu screwdriver) Touran Wolfsburg	**manual** (manipulator without sensors and accu screwdriver) Golf A5 Uitenhage
Placing spare wheel in boot	**automatic** (1 robot) Golf A5 Wolfsburg	**manual** (manipulator) Touran Wolfsburg	**manual** Golf A5 Uitenhage
Pre-mounting/ Fitting wheels	**automatic** (4 facilities) Golf A5 Wolfsburg	**manual** (2 supporters, accu screw-driver and 2 manipulator) Touran Wolfsburg	**manual** (electrical screwdriver) Golf A5 Uitenhage

Appendix B

<u>Morphological boxes:</u>

Possibilities of assembling

Appendix A3: Excerpt of QUASI FI Top500 list

QUASI-Feldinformationen
Stand 03/06-06.04.06 16:50
User EB0KLMK
Seite 14 / 16

Topliste nach KDNR

VW, Golf Limousine, Wolfsburg, Markt: DEUTSCHLAND

MJ 2006

Vertraulich
ohne PR-Nummern

Rang	KDNR	Beschreibung	Ges%	SF Gesamt	AT%	EUR pro SF	EUR Gesamt	%	Schadensart	%	Schadensart	%	Schadensart
425	3405	Schalthebel	0	6	0	28,07	168	50	LEICHTGAENGIG (EIN	33	SCHWERGAENGIG (KLE	17	LIEGENBLEIBER
426	3712	Abdeckung f Wählhebel	0	6	100	134,29	806	33	MECHANISCHE FEHL	33	OPTISCHE SCHAEDEN	17	GERISSEN,GEBROCHE
427	4007	Aggregateträger	0	6	17	99,92	599	50	GERAEUSCHE	33	LEICHTGAENGIG (EING	17	MECHANISCHE FEHLE
428	5305	Abschlußblech hinten	0	6	0	64,84	389	67	MECHANISCHE FEHL	33	UNDICHT		
429	5837	Innenbetätigung f Türsch	0	6	17	54,18	325	67	MECHANISCHE FEHL	33	LEICHTGAENGIG (EING		
430	6457	Fensterkurbel	0	6	50	12,56	75	50	MECHANISCHE FEHL	50	LEICHTGAENGIG (EING		
431	6460	Türfensterscheibe hinten	0	6	83	143,53	861	50	OPTISCHE SCHAEDE	17	FALSCHES SERIENTEI	17	GERISSEN,GEBROCHE
432	6489	Heckfensterscheibe getö	0	6	83	224,14	1.345	33	OPTISCHE SCHAEDE	17	GERISSEN,GEBROCHEI	17	ELEKTRISCHE FEHLE
433	6912	Dreipunktgurt hinten	0	6	67	103,91	623	67	SCHWERGAENGIG (K	17	LEICHTGAENGIG (EING	17	GERAEUSCHE
434	7017	Dämpfung f Motorraum	0	6	67	34,94	210	83	FEHLENDES SERIENT	17	LEICHTGAENGIG (EING		
435	7058	Zierleiste f Schalttafel	0	6	67	283,80	1.703	33	OPTISCHE SCHAEDE	17	FALSCHES SERIENTEI	17	LEICHTGAENGIG (EIN(
436	7228	Höhenverstellung	0	6	17	50,27	302	50	LEICHTGAENGIG (EIN	33	SCHWERGAENGIG (KLE	17	GERISSEN,GEBROCHE
437	7255	Sitzgestell hinten	0	6	0	27,43	165	50	GERAEUSCHE	33	MECHANISCHE FEHLEF	17	GERISSEN,GEBROCHE
438	7286	Schalter f Sitzverstellung	0	6	100	135,22	811	83	ELEKTRISCHE FEHLE	17	LIEGENBLEIBER		
439	7429	Heizelement f Lehne vorr	0	6	83	181,24	1.087	100	ELEKTRISCHE FEHLE				
440	8238	Temperaturfühler	0	6	83	302,95	1.818	50	ELEKTRISCHE FEHLE	17	LEICHTGAENGIG (EING	17	LIEGENBLEIBER
441	8274	Magnetventil	0	6	100	211,31	1.268	33	ELEKTRISCHE FEHLE	17	FAHRZEUGWANDLUNG	17	UNDICHT
442	8525	Vorwiderstand f Gebläse	0	6	100	60,34	362	100	ELEKTRISCHE FEHLE				
443	8714	Fotosensor	0	6	33	44,02	264	50	GERAEUSCHE	33	MECHANISCHE FEHLEF	17	ELEKTRISCHE FEHLE
444	8745	Leitung Kompressor-Verc	0	6	50	215,18	1.291	67	UNDICHT	33	MECHANISCHE FEHLEF		
445	9082	Zigarrenanzünder	0	6	33	48,71	292	50	ELEKTRISCHE FEHLE	33	MECHANISCHE FEHLEF	17	FEHLENDES SERIENT
446	9161	Fernbedienung	0	6	83	170,51	1.023	83	ELEKTRISCHE FEHLE	17	FALSCHES SERIENTEI		
447	9668	Steuergerät f Wegfahrsp€	0	6	0	63,59	382	83	ELEKTRISCHE FEHLE	17	LIEGENBLEIBER		
448	9672	Leseeinheit f Wegfahrspe	0	6	17	88,08	528	100	ELEKTRISCHE FEHLE				
449	9734	Faltenbalg	0	6	67	95,00	570	50	GERISSEN,GEBROCH	50	LEICHTGAENGIG (EING		
450	1083	Abdeckung	0	5	40	72,39	362	40	MECHANISCHE FEHL	20	GERISSEN,GEBROCHEI	20	GERAEUSCHE
451	1705	Öldruckschalter	0	5	60	64,26	321	40	ELEKTRISCHE FEHLE	40	UNDICHT	20	LIEGENBLEIBER
452	1751	Dichtung f Ölwanne	0	5	40	193,73	969	80	UNDICHT	20	GRENZFAELLE DER MO		
453	2065	Relais f Kraftstoffpumpe	0	5	100	69,82	349	60	ELEKTRISCHE FEHLE	40	LIEGENBLEIBER		
454	2078	Pedalwertgeber	0	5	60	140,97	705	80	ELEKTRISCHE FEHLE	20	LEICHTGAENGIG (EING		
455	2143	Ladeluftkühler	0	5	20	177,75	889	60	MECHANISCHE FEHL	20	GERISSEN,GEBROCHEI	20	UNDICHT
456	2471	Geber f Saugrohrdruck	0	5	100	243,71	1.219	80	LIEGENBLEIBER	20	ELEKTRISCHE FEHLE		
457	2630	Mittelschalldämpfer	0	5	0	56,27	281	80	GERAEUSCHE	20	LEICHTGAENGIG (EING		

Fahrzeuge: 64.050; Verkauft: 47.131; Stichprobe: 43.546

ST TOP 500 WOB Golf A5_TOP

Appendix A3: QUASI FI Top500 list p.14 of 16, Source: Department H. Sommer (2006)

Appendix A2: QRK-Philosophie

Volkswagen

Wolfsburger Montagen Produktions System
QRK-Philosophie

1

Appendix A2: QRK-Philosophie p. 1, Source: Department Organisationsentwicklung CC Montagen (2004)

Wolfsburger Montagen Produktions System
QRK - Philosophie

Volkswagen

Qualität, Image und Konkurrenz

Das Image einer Marke ist langlebig und entscheidend für den Konkurrenzkampf zwischen verschiedenen Herstellern:

VW; gutes Image („ er läuft und läuft...)
Meißner Porzellan
Leica

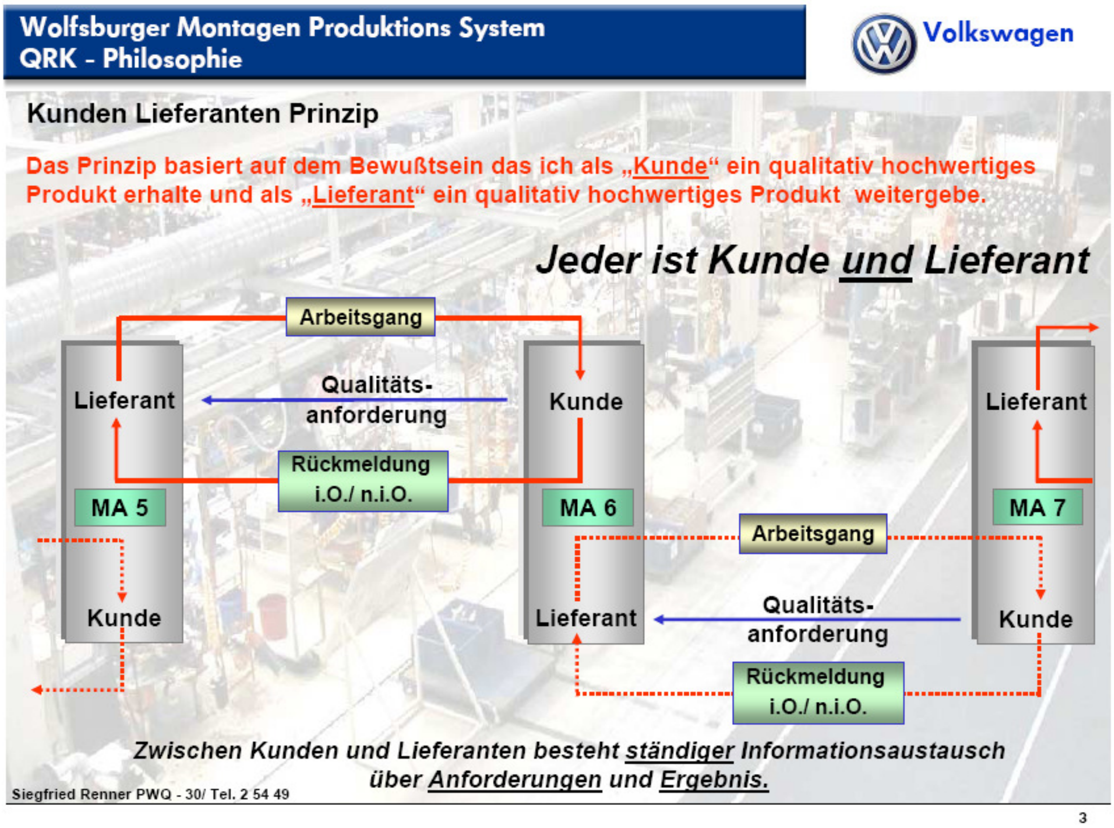
Ein Unternehmen mit guter Qualität und gutem Image kann über den Preis Konkurrenten aus dem Markt verdrängen.

Der Aufbau eines guten Images dauert viel länger als dessen Verlust:

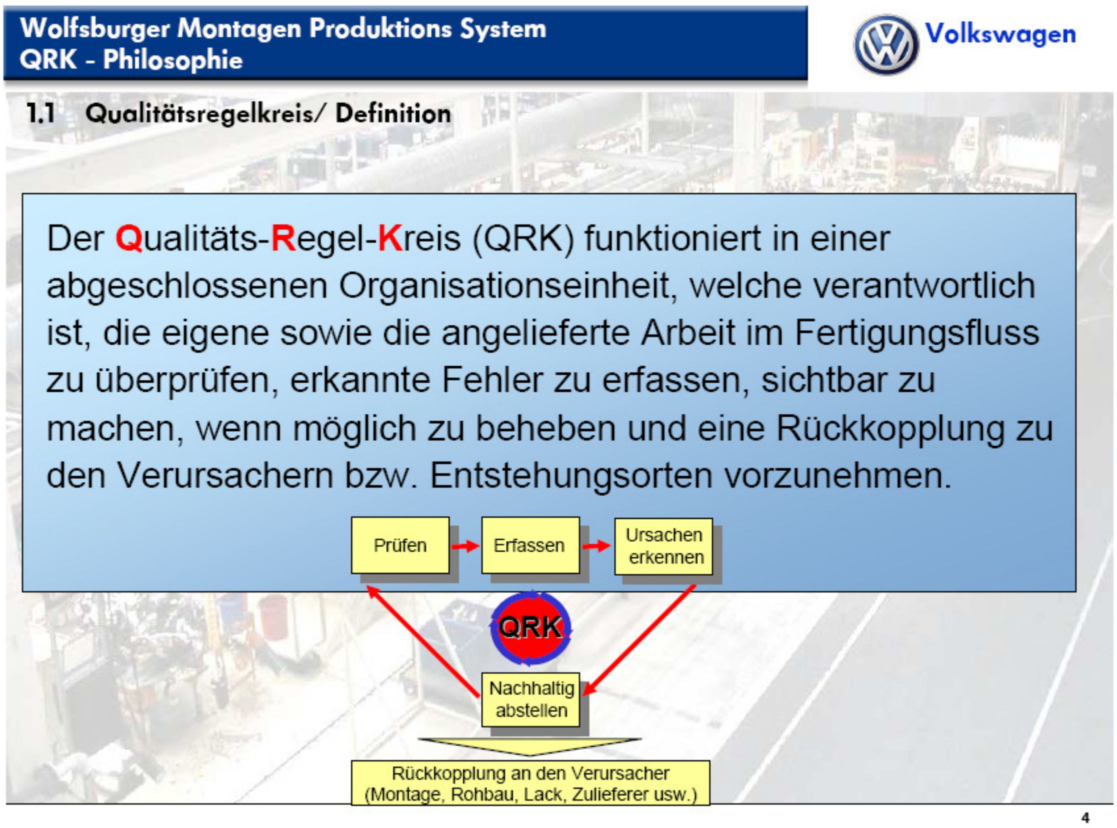
Schlechte Erfahrungen werden durchschnittlich *acht* anderen Personen mitgeteilt, positive im Durchschnitt nur *zwei* anderen!

2

Appendix A2: QRK-Philosophie p. 2, Source: Department Organisationsentwicklung CC Montagen (2004)

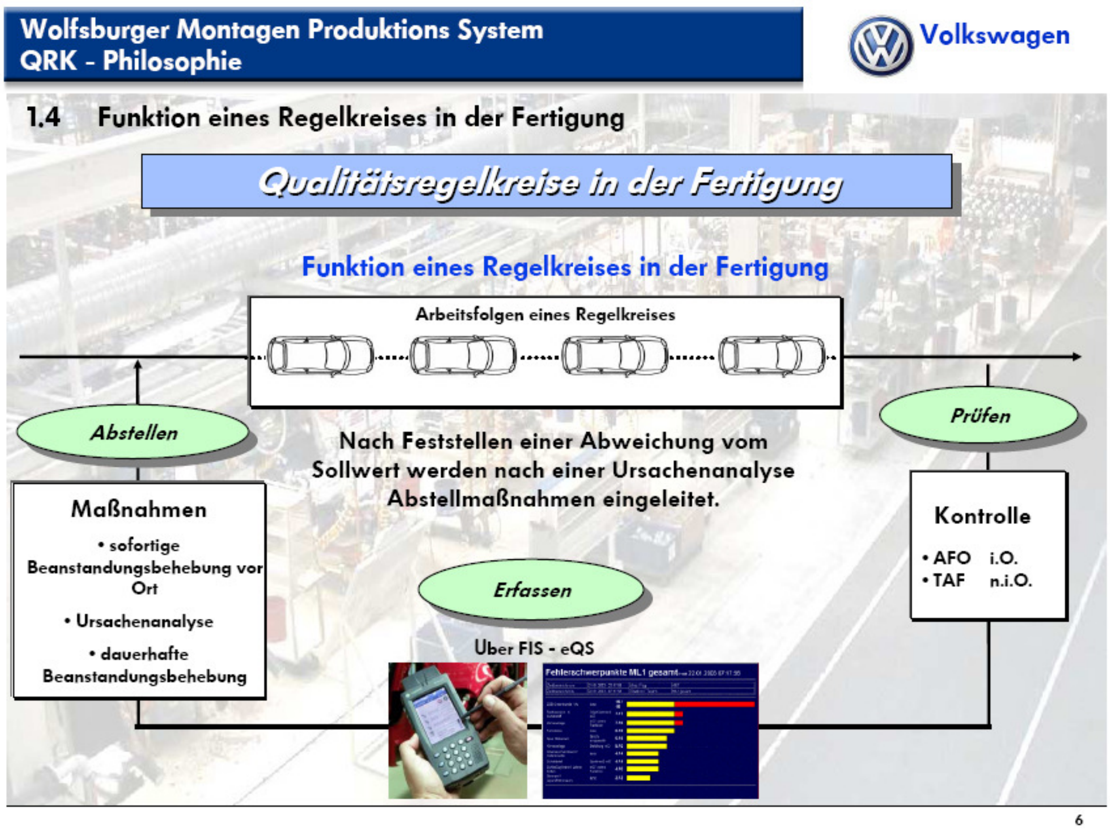


Appendix A2: QRK-Philosophie p. 3, Source: Department Organisationsentwicklung CC Montagen (2004)



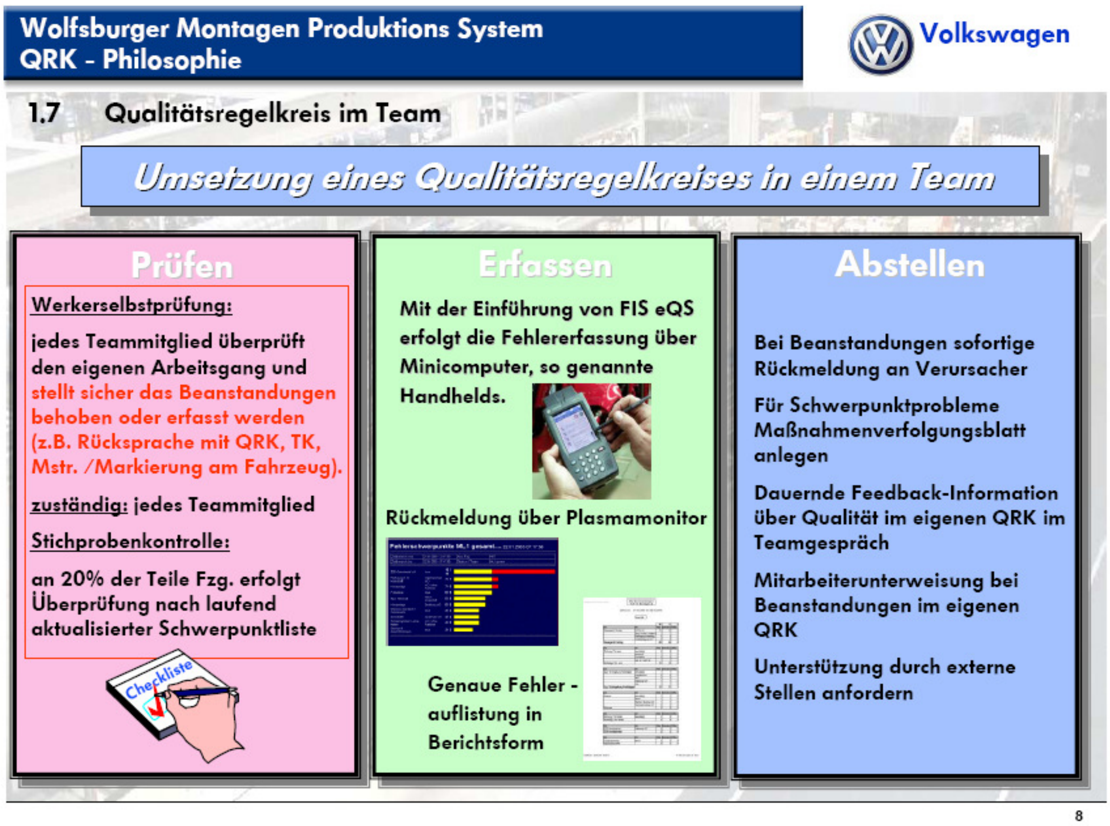
Appendix A2: QRK-Philosophie p. 4, Source: Department Organisationsentwicklung CC Montagen (2004)

Appendix A2: QRK-Philosophie p. 5, Source: Department Organisationsentwicklung CC Montagen (2004)



Anhang A2: QRK-Philosophie p. 6, Source: Department Organisationsentwicklung CC Montagen (2004)

Appendix A2: QRK-Philosophie p. 7, Source: Department Organisationsentwicklung CC Montagen (2004)



Appendix A2: QRK-Philosophie p. 8, Source: Department Organisationsentwicklung CC Montagen (2004)

Appendix A1: Qualitätspolitik im Volkswagen Konzern

VOLKSWAGEN EXCELLENCE

Qualitätspolitik im Volkswagen Konzern

VOLKSWAGEN AG

Volkswagen – die Erfolgreichsten

Mit exzellenten Produkten und Dienstleistungen in allen Marken und Gesellschaften will der Volkswagen Konzern als Global Player seine Kunden auf der ganzen Welt begeistern und überragende Geschäftsergebnisse erreichen. Dem erklärten Ziel VOLKSWAGEN EXCELLENCE entspricht eine am langfristigen Unternehmenserfolg orientierte Qualitätspolitik, die alle Mitarbeiterinnen und Mitarbeiter verstärkt auf Kunden und Prozesse ausrichtet.

Dr. B. Pischetsrieder
Vorstandsvorsitzender
der Volkswagen AG
Qualitätssicherung
Forschung u. Entwicklung
Vertrieb und Marketing

Dr. B. Adelt
Controlling und Rechnungswesen

Dr. P. Hartz
Personal, Arbeitsdirektor

F. J. Garcia Sanz
Beschaffung

Dr. F. Weißgerber
Produktion

Dr. J. Neumann
Konzernstrategie, Treasury
Recht, Organisation

F. Schling
Konzern-Qualitätssicherung

Dr. M. Winterkorn
Audi AG
Vorstandsvorsitzender

H. D. Pötsch
Controlling und Rechnungswesen

September 2003

Kundenorientierung

Wir stellen die Erwartungen unserer externen und internen Kunden in den Mittelpunkt unseres Handelns. Maßstab für den Erfolg ist dabei die Zufriedenheit der Kunden mit unseren Leistungen und ihre Loyalität gegenüber dem Unternehmen.

Ergebnisorientierung

Für Volkswagen ist wettbewerbsüberlegene Qualitätsleistung der Schlüssel, um unter Berücksichtigung der Interessen von Kunden, Mitarbeiterinnen und Mitarbeitern, Lieferanten, Händlern und der Gesellschaft langfristig überragende Geschäftsergebnisse zu erzielen.

Führung und Zielkonsequenz

Wir handeln strukturiert und systematisch aufeinander abgestimmt. Hervorragende Leistungen erreichen wir durch die strategische Ausrichtung VOLKSWAGEN EXCELLENCE sowie durch das Qualitätsbewusstsein und das Engagement unserer Führungskräfte und Mitarbeiterinnen und Mitarbeiter.

Prozessorientiertes Management

Durch konsequente Prozessorientierung und -bewertung gewährleisten wir schnelle Zielerreichung bei optimalem Ressourceneinsatz. Entscheidungen werden auf Basis von Fakten und strategischer Ausrichtung getroffen.

Mitarbeiterentwicklung und -beteiligung

Wir alle bestimmen die Qualität und den Erfolg unserer Leistungen. Durch aktive Beteiligung fördern wir qualifizierte und eigenverantwortlich handelnde Mitarbeiterinnen und Mitarbeiter.

Kontinuierliches Lernen, Innovation und Verbesserung

Durch Kreativität und Lernen entwickeln sich alle Mitarbeiterinnen und Mitarbeiter kontinuierlich weiter. Unser ständiger Verbesserungsprozess gründet auf gezieltem Methodeneinsatz sowie effektivem Wissensaustausch und misst sich im Vergleich mit den Besten.

Aufbau von Partnerschaften

Partnerschaftliches Verhalten gegenüber unseren Lieferanten, Händlern und anderen Organisationen verschafft uns beständige Geschäftsbeziehungen, die sich durch beiderseitigen Nutzen auszeichnen.

Verantwortung gegenüber der Öffentlichkeit

Umwelt- und soziale Kompetenz schaffen Vertrauen in der Öffentlichkeit. Durch schonenden Umgang mit Ressourcen während des gesamten Lebenszyklus unserer Produkte steigern wir unsere Glaubwürdigkeit und Wertschätzung.

Appendix A1: Qualitätspolitik im Volkswagen Konzern, Source: Konzern Qualitätssicherung (2003)

Appendix A

<u>Level of specific VW knowledge:</u>

QRK-Philosophy, Q-Policy and Excerpts of used presentations

Table of contents

Matrixes with final results

AP1 opt.	A	B	C	D	E	F	G	H	I	J	K	L	M
Manufacturing stations / Level of automation	Rollforming tailgate	Fitting cockpit location brackets	Rollforming doors	Cleaning window flange, Closing tailgate	Priming window flange, Opening bonnet	Applying cockpit glue	Cockpit fitting 1	Removing cable box, Remaining screw connections	Remaining screw connections	Cockpit fitting 2	Removing cable box, Remaining screw connections	Remaining screw connections	Total
Level of automation 3 (practical)	myprocess (T.C./veh.) 0,00188	FISeQS (T.C./veh.) 0,00003	myprocess (T.C./veh.) 0,00229	myprocess (T.C./veh.) n. a./n. d.	myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.)				FISeQS (T.C./veh.) 0,01543		FISeQS (T.C./veh.) 0,01988
Opt. level of automation (theoretical corrected)	myprocess (T.C./veh.) 0,00188	FISeQS (T.C./veh.) 0,00003	myprocess (T.C./veh.) 0,00229	FISeQS (T.C./veh.) 0,00002	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n.d.					FISeQS (T.C./veh.) 0,01543		FISeQS (T.C./veh.) 0,01965
Level of automation (optimal)	myprocess (T.C./veh.) 0,00188	FISeQS (T.C./veh.) 0,00003	myprocess (T.C./veh.) 0,00229	myprocess (T.C./veh.) n. a./n. d.	myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.)				FISeQS (T.C./veh.) 0,01543		FISeQS (T.C./veh.) 0,01988

Assembly Part 1, optimal level of automation

AP2 opt.	A	B	C	D	E	F	G	H	I
Manufacturing stations / Level of automation	Stamping vehicle identification number (VIN) (3 times)	Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	Fitting gear shift	Closing bonnet	Lifting down	Fitting windscreen 1, Fitting rear glass 1	Fitting windscreen 2, Fitting rear glass 2	Fitting side glasses	Total
Level of automation 4 (Auto5000 WOB) (practical)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00645	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,01392		myprocess (T.C./veh.) 0,00293	myprocess (T.C./veh.) 0,02330
Opt. level of automation (theoretical corrected)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00645	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,01392		myprocess (T.C./veh.) 0,00293	FISeQS (T.C./veh.) 0,02330
Level of automation (optimal)	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,00645	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) n. d.	myprocess (T.C./veh.) 0,01392		myprocess (T.C./veh.) 0,00293	myprocess (T.C./veh.) 0,02330

Assembly Part 2, optimal level of automation

AP3 opt. Manufactu-ring stations / Level of automation	A Opening bonnet	B Putting in/Fitting the CW trim panel	C Putting in battery	D Fitting battery	E Fitting cross member	F Fitting rear bumper	G Fitting frontend	H Fitting front bumper	I Placing spare wheel in boot	J Pre-mounting/Fitting wheels	K Total
Level of automation 1 (Golf A5 WOB) (practical)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00109	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.) 0,00061	FISeQS (T.C./veh.) **0,00737**
Opt. level of automation (theoretical corrected)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00109	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		myprocess (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00061	FISeQS (T.C./veh.) **0,00711**
Level of automation (optimal)	FISeQS (T.C./veh.) n. d.	FISeQS (T.C./veh.) 0,00109	FISeQS (T.C./veh.) 0,00067		FISeQS (T.C./veh.) 0,00013	FISeQS (T.C./veh.) 0,00082	FISeQS (T.C./veh.) 0,00379		FISeQS (T.C./veh.) 0,00025	FISeQS (T.C./veh.) 0,00061	FISeQS (T.C./veh.) **0,00737**

Assembly Part 3, optimal level of automation

AP1 opt.	A	B	C	D	E	F	G	H	I	J	K	L
Manufacturing stations / Level of automation	Rollforming tailgate	Fitting cockpit location brackets	Rollforming doors	Cleaning window flange, Closing tailgate	Priming window flange, Opening bonnet	Applying cockpit glue	Cockpit fitting 1	Removing cable box, Remaining screw connections	Remaining screw connections	Cockpit fitting 2	Removing cable box, Remaining screw connections	Remaining screw connections
Level of automation 3 (practical)	manual (handrollfor-ming device)	automatic (2 facilities)	manual (handrollfor-ming device)	manual	manual	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)
Opt. level of automation (theoretical corrected)	manual (handrollfor-ming device)	automatic (2 facilities)	manual (handrollfor-ming device)	automatic (3 robots)	manual	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)
Level of automation (optimal)	manual (handrollfor-ming device)	automatic (2 facilities)	manual (handrollfor-ming device)	manual	manual	automatic (1 robot)	automatic (2 facilities)			automatic (2 facilities)	manual (electrical screwdriver)	automatic (1 robot)

Assembly Part 1, optimal level of automation

	AP2 opt. Manufacturing stations / Level of automation	Level of automation 4 (Auto5000 WOB) (practical)	Opt. level of automation (theoretical corrected)	Level of automation (optimal)
A	Stamping Vehicle Identification Number (VIN) (3 times)	manual (3 manipula-tors)	manual (3 manipula-tors)	manual (3 manipula-tors)
B	Lifting up and fitting complete powertrain, Underbody work and screwing all bolts	automatic (18 facilities, 1 robot and 1 lifter)	automatic (18 facilities, 1 robot and 1 lifter)	automatic (18 facilities, 1 robot and 1 lifter)
C	Fitting gear shift	manual (accu screw-driver)	manual (accu screw-driver)	manual (accu screw-driver)
D	Closing bonnet	manual	automatic (1 robot) / manual	manual
E	Lifting down	automatic (3 facilities and 1 lifter)	automatic (3 facilities and 1 lifter)	automatic (3 facilities and 1 lifter)
F	Fitting windscreen 1, Fitting rear glass 1	manual (2 robots)	manual (2 robots)	manual (2 robots)
G	Fitting windscreen 2, Fitting rear glass 2			
H	Fitting side glasses	manual (1 robot)	manual (1 robot)	manual (1 robot)

Assembly Part 2, optimal level of automation

AP3 opt.	A	B	C	D	E	F	G	H	I	J
Manufacturing stations / Level of automation	Opening bonnet	Putting in/Fitting the CW-trim panel	Putting in battery	Fitting battery	Fitting cross member	Fitting rear bumper	Fitting frontend	Fitting front bumper	Placing spare wheel in boot	Pre-mounting/Fitting wheels
Level of automation 1 (Golf A5 WOB) (practical)	automatic (1 facility)	automatic (2 facilities)	automatic (1 robot and 0,5 manipulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)
Opt. level of automation (theoretical corrected)	automatic (1 facility) manual	automatic (2 facilities)	automatic (1 robot and 0,5 manipulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		manual (manipulator)	automatic (4 facilities)
Level of automation (optimal)	automatic (1 facility)	automatic (2 facilities)	automatic (1 robot and 0,5 manipulator)	automatic (1 robot)	automatic (2 robots and 1 facility)	automatic (1 robot and 1 facility)	automatic (1 robot and 1 facility)		automatic (1 robot)	automatic (4 facilities)

Assembly Part 3, optimal level of automation