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Case Study: Automation Strategies at Volkswagen

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In the global automotive industry, for decades, vehicle manufacturers have continually increased the level of automation of production systems in order to be competitive. However, there is a new trend to decrease the level of automation, especially in final car assembly, for the reasons of flexibility and economy. With the increasingly competitive automotive market, corporations often must make a choice of a plant location for production of certain vehicle models. The plant location is linked to the level of automation as it has a direct impact on the quality and cost of a product, but also depends on the level of skills and the availability of labour resources in a particular region.

In this case study, Volkswagen AG (*VW*) production sites in Germany and South Africa are analysed in order to obtain the best level of automation based on cost, productivity, quality and flexibility, for a particular plant location. The result of the analysis indicates that the highest level of automation is not necessarily the best in terms of cost and quality, and some de-automation is required. On the other hand, the analysis also shows that a low automation level is the main reason for poor product quality and low productivity. Hence, the best automation strategy is formulated on the basis of the analysis of all the aspects of the process in the local context, such as productivity, costs, quality and flexibility.

***Index Terms*—Automation, assembly, competitiveness**

I. Introduction

Today, the automotive industry is the epitome of mass production, mass marketing and mass consumption. 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. Hence, an urge for progressive automation arose in the past, since it seemed to be the only strategy to be competitive. However, a high level of automation can lead to less flexible automation systems and the products are difficult to customise or to extremely complex automation systems, which are expensive. Therefore, the choice of level of automation of a production system is an important management decision.

The *VW* procedure for introducing a new vehicle is represented in Fig. 1 showing that plant location plays an important role in process planning and preparation. The choice of plant location depends, among others, on the personnel and energy costs, the level of education, skills and motivation of personnel, and the market conditions. On the other hand, the plant location determines the level of automation of assembly lines.

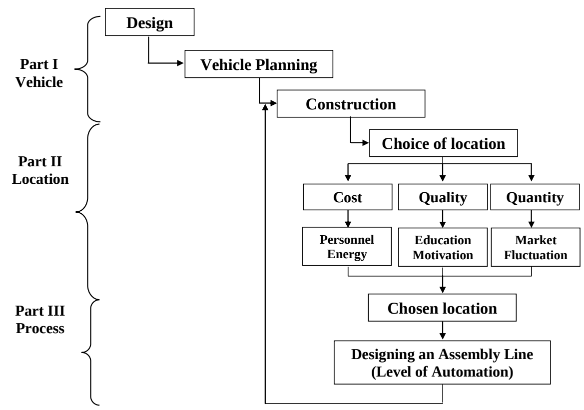

Fig. 1. General procedure for introducing a new vehicle

The analysis of the assembly lines of *VW* at the three production sites was done in order to determine the automation/de-automation strategies by combining aspects of manufacturing systems such as costs, productivity, quality and flexibility. The sites studied in this research are the *Golf A5* assembly line at the mother plant in Wolfsburg, the *Touran* assembly line at the *Auto5000 GmbH* in Wolfsburg and the *Golf A5* assembly line in Uitenhage, South Africa. The aim of the analysis is to determine optimal levels of automation at the three production sites in order to make recommendations to automate or de-automate particular sections of the assembly processes.

II. Background

A. Level of Automation

The level of automation represents the portion 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. The level of automation can be represented by a ratio of the number of automated functions to the total of all functions [1]. However, this requires that all functions be equally matched otherwise weighting factors should be incorporated.

B. Manufacturing Costs

The total cost per unit as dependant on the level of automation can be represented graphically as shown in Fig. 2 [2]. As can be seen, the personnel costs decrease proportionally to the growing level of automation. At a low automation level, simple and economically justifiable operations are automated, therefore the automation cost increase almost linearly. Further on, the expenditure increases over-proportionally because of the rising complexity of the system. Hence, reaching complete automation causes the automation cost to increase exponentially while the personnel costs decrease only linearly, indicating a higher total cost.

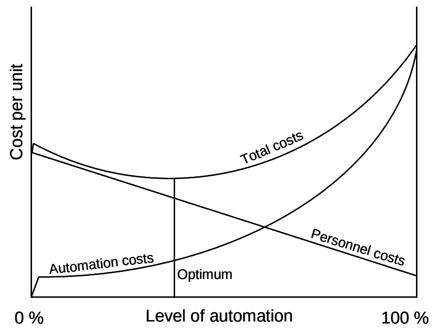

Fig. 2. Graph of cost versus level of automation

For the costs calculations, the relevant cost approach is used, where only the costs that make the largest contribution are taken into account [3].

The following cost types are necessary for the realisation of the assembly process:

- Personnel (all carrying out and planning activities in the assembly process; personnel costs consist of wages or rather salary and social costs; they essentially depend on personnel qualification)
- Operating material (installations for assembly and transport; operating material costs include all costs for running the operating material)
- Material (only consumables are relevant)
- Information (software and hardware; already included in operating material)

C. *Quality Indices*

Quality is a top priority competition factor that should be integrated into all the processes of a company. Quality is characterised by the index system, which is defined as a compilation of quantitative variables, in which individual indices belong to each other, are supplementary to each other or explain each other in an objective and practical way. Thus, all these collected factors are focused on one common paramount target. An index is formed by the following elements: character of information, ability to quantify facts, and specific form of information [4]. All the information in the index should be adequately defined to avoid ambiguity.

For manufacturing and assembly processes, the quality standards are specified by the output quality indices, which are as follows:

- The quota of quality defects that does not meet the quality requirements in production immediately, i.e. the ratio of the defects to the whole production volume.
- The indices concerning the number of rejects and the rectification of rejects as well as their prevailing share of the whole production volume that shows the developing trend.
- The indices with regard to the individual/different types of defects in their relation to the total number of defects in the production.
- The indices referred to as customer complaints that are an indication of quality defects which have remained undiscovered in the production process.
- Audit-Notes, which are determined and assessed separately as indices by a company.

D. *Productivity Indices*

The productivity indices are determined from the number of quantitative aspects, such as ‘hard’ facts and ‘soft’ facts. ‘Hard’ facts are:

- The number of units that are planned to be built, the so-called scheduled number of units.
- The number of units that have actually been built.
- Times like the cycle times, manufacturing times, downtimes and total working times.
- Number of employees involved in the production process.

These are set in relation to:

- The availability of a production system with respect to the amount of standstill losses.
- The decreasing degree of performance with respect to loss of speed.
- The degree of quality depending on the number of parts which are produced with defects.
- The effectiveness of equipment as a whole with respect to the availability of production, the degree of performance and quality.
- Productivity which refers to the average number of vehicles built by one employee during a specified period of time and the number of vehicles built by all employees per hour.

‘Soft’ facts include:

- Flexibility to manufacture different units.
- The degree of complexity and its dependence on the different range of vehicle models compared to the basic model.
- Flexibility with regard to the possibility of producing many variations of a product on one line.

All the cost, quality and productivity aspects are used for determining the best level of automation of the assembly processes at the three production sites as shown in the following section.

III. Analyses of the Assembly Processes

A. *Levels of Automation*

The analysis was done for the final assembly of the *Golf A5* and *Touran* models in Germany and the *Golf A5* model in South Africa. The assembly processes are implemented at different levels of automation providing the possibility of comparing and determining the best

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automation strategy for the particular plant location. The final assembly consists of three main processes called Assembly Parts. Each Assembly Part in turn can be divided into Assembly Operations or Stations. Assembly Part 1 consists of five Assembly Stations and includes roll forming of the *tailgate* and *doors* and the fitting of a *cockpit*. Assembly Part 2 also consists of five Assembly Stations and includes mainly the fitting of a *power train* and *glasses*. Assembly Part 3 includes seven Assembly Stations, which are typically the fitting of *trim panels*, a *cross member*, a *bumper*, a *front end*, *wheels* and a *battery*.

To determine the level of automation, the Assembly Parts are placed in a matrix with Assembly Stations shown in columns and different manufacturing methods in rows according to the level of automation from the highest to the lowest (Table 1). The starting point of creating the levels of automation begins at the assembly of the *Golf A5* model at Wolfsburg because this process is the most automated and therefore it is assigned the first level of automation. By de-automating one station at a time, the level of automation decreases. For example, Assembly Part 1 has five levels of automation because it includes five Assembly Stations. The same is true for Assembly Part 2, whereas Assembly Part 3 has seven levels of automation due to seven Assembly Stations. The last level of automation is manual assembly, which is the way the *Golf A5* model is assembled in Uitenhage. In between, there is one level of automation that represents how the *Touran* model is assembled in Germany, which is a combination of the automated and manual stations.

For all the stations of the Assembly Parts, the cycle times and the number of personnel are determined based on the available information from the three production methods and their combinations. The results are matrices with different levels of automation and the number of necessary personnel for each station.

Table 1. Example of Assembly Part 1 Matrix

Manufacturing stations / Level of automation	Rollforming tailgate	Fitting cockpit location brackets	Rollforming doors	Cleaning window flange, Closing tailgate	Priming window flange, Opening bonnet	....
Level of automation 1 (Golf A5 WOB)	automatic (1 robot)	automatic (2 facilities)	automatic (4 robots)	automatic (3 robots)	automatic (3 robots)	....
⋮	⋮	⋮	⋮	⋮	⋮	
Level of automation 5 (Golf A5 SA)	manual (handrollfor-ming device t_M: 1,07 min) t_{QCC}: 0,28 min	manual (electrical screw-driver and jigs t_M: 2,55 min) t_{QCC}: 0,14 min	manual (handrollfor-ming 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	....

After establishing the matrices, the basis for further analysis of each production site is created. Then separate analyses of each production site can start.

B. *Manufacturing Costs*

If every created level of automation (in the matrices) is provided with costs, the result will be the representation of all relevant costs that are differentiated to resources depending on the different levels of automation. By adding up the different costs of all stations, the most economical solution and with it, the most economical level of automation of each matrix can be determined.

By adding up all the total costs per unit of each Assembly Station, the total costs per unit of the whole Assembly Part for a specified level of automation is determined for each production site. Due to differences in labour and running costs, each production site will have different total costs for the same Assembly Part. The total costs per unit for assembly of the *Golf A5* model in Germany are shown in Table 2. The actual costs have been changed for confidentiality.

Table 2. Unit costs of the assembly stations of *Golf A5* in Germany

Level of automation	Assembly Part 1	Assembly Part 2	Assembly Part 3
1	1,00 €	1,20 €	1,20 €
2	1,10 €	1,30 €	1,10 €
3	1,20 €	1,10 €	1,10 €
4	1,30 €	1,00 €	1,00 €
5	1,40 €	1,40 €	1,30 €
6			1,40 €
7			1,50 €

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. This level also predominates in practice (dotted fields). Therefore Assembly Part 1 is designed optimally. The workers and the investment costs constitute the highest share of the total costs per unit. The cockpit fitment is the most expensive station in this Assembly Part. With a decreasing level of automation, the other workers and investment costs take a smaller and smaller part but costs for direct workers in the line increase accordingly. This is the main reason why even the second level of automation is already more expensive than the first. The other types of cost only take a small part of the total costs per unit.

In Assembly Part 2, the fourth level of automation is optimal. The costs of workers in the line increase, whereas, on the other hand, the costs for all the other workers as well as investment in equipment do not increase in the same way. Thus, in order to reach the optimal level of automation, the stations stamping vehicle identity numbers, fitting the gearshift, closing the bonnet and fitting all the windows have to work in the same way as in the assembly line of the *Auto5000 GmbH*.

In Assembly Part 3, the fourth level of automation is also optimal. On the first level, the investment costs constitute the highest part of the total costs per unit, followed by the personnel costs for maintenance, reworkers and other workers. As in Assembly Part 2, the costs for workers in the line increase with decreasing automation, while costs for reworkers, other workers and maintenance decrease until the cost optimum is reached in level 4. After that the costs for workers in the line increase accordingly, which makes every further de-automation uneconomical. In order to put level 4 as an optimal level of automation into practice, the stations opening the bonnet, putting in and fitting the trim panel, putting in and fitting a *battery*, fitting a *cross member* as well as a *rear bumper* have to be designed as in the *Auto5000 GmbH*. The total costs per unit for the assembly operations of the *Touran* model at the *Auto5000 GmbH* are shown in Table 3.

Table 3. Unit costs of the assembly stations of *Touran* in Germany

Level of automation	Assembly Part 1	Assembly Part 2	Assembly Part 3
1	1,30 €	1,20 €	1,30 €
2	1,20 €	1,30 €	1,20 €
3	1,00 €	1,10 €	1,10 €
4	1,10 €	1,00 €	1,00 €
5	1,40 €	1,40 €	1,40 €
6			1,50 €
7			1,60 €

As can be seen, for Assembly Part 1, the third level of automation is optimal. At this level, the highest costs per unit are the workers on the line, followed by the investment costs. But in practice, the actual automation level is level 4 (dotted fields). To reach the optimal level, the stations fitting cockpit location brackets and cockpit fitting 1 and 2 have to be designed to be fully automatic as is the case with the *Golf A5* model assembly line.

In Assembly Part 2, the fourth level of automation is the optimal level. 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 under bodywork.

In Assembly Part 3, the fourth level of automation also represents the optimum but in practice level 6 predominates, which again requires a higher level of automation in the assembly line of the *Touran* model at the *Auto5000 GmbH*. On level 6, the fitting of the front end is the most expensive station because of the high personnel costs for workers in the line. The second most expensive station is the pre-mounting and fitting of wheels. Both of the stations have high investment costs as well. Therefore, both of these stations and the station placing the *spare wheel* in *the boot* should work fully automatically as it is done in the *Golf A5* model assembly line at the same location.

For the *Golf A5* model produced in South Africa (Table 4), most of the manual levels of automation reach the optimal level, and manual levels are currently implemented. Therefore, in this step of the analysis, no changes of stations or other operations are necessary. In Assembly Part 1, the most expensive station is fitting the cockpit. It takes nearly half of the total costs per unit. In Assembly Part 2, fitting the power train combined with the whole under bodywork takes the highest costs per unit, which is even more than half of the total costs per unit. In Assembly Part 3, pre-mounting and fitting of wheels show the highest part of the total costs. It is possible that the costs can be reduced further by reducing the level of automation at the production site in South Africa. However, there are no data available about manufacturing times and costs for facilities with even less automation. Also, further de-automation could lead to bad quality.

Table 4. Unit costs of the assembly stations of *Golf A5* in Uitenhage

Level of automation	Assembly Part 1	Assembly Part 2	Assembly Part 3
1	1,40 €	1,40 €	1,60 €
2	1,30 €	1,30 €	1,50 €
3	1,20 €	1,20 €	1,30 €
4	1,10 €	1,10 €	1,20 €
5	1,00 €	1,00 €	1,10 €
6			1,40 €
7			1,00 €

C. Quality

The quality indices for the three production sites are put in one table as shown in Table 5. These include *Field data*, *Audit data* of vehicle and process, *Vehicle Preparation Centre* (*VPC*) data and *Direct Runner Rates* (*DRR*). Field data show the quality of vehicles from a customer's point of view with the recordings of *trouble cases* (*TC*) per vehicle. Vehicle auditing is an element of the *Quality Assurance System*, which judges the effectiveness of the *Quality Management System* on the basis of quality delivered in a snapshot. The *Vehicle Preparation Centre*, located in Japan, records defects in vehicles delivered from Wolfsburg and Uitenhage in a 100% control. *DRR* is an index by which each plant is measured. It indicates the number of vehicles which at the final checkpoint (*CP8*) of the production process get an o.k.-status. *DRR* is also included on *CP7* to show how many o.k.-vehicles have been released from the assembly. The effectiveness of the Quality Management Systems is judged by the Process Audits expressed as a percentage.

Table 5. Matrix of quality data

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)	0,01345 T.C./veh.	0,02796 T.C./veh.	0,00465 T.C./veh.	0,05432 T.C./veh.	80 (90) Audit Points	2,44 T.C./veh.	58 / 62 %	94 %
Level of automation (Auto5000 WOB)	0,03872 T.C./veh.	0,01235 T.C./veh.	0,01987 T.C./veh.	0,01076 T.C./veh.	82 (90) Audit Points	0.87 T.C./veh.	69 / 95 %	91 %
Level of automation (Golf A5 SA)	0,10984 T.C./veh.	0,03561 T.C./veh.	0,96543 T.C./veh.	0,02345 T.C./veh.	92 (90) Audit Points	2,23 T.C./veh.	81 / 89 %	92 %

The next step is the investigation into finding the optimal level of automation regarding quality. All other quality factors can only be concluded from these results, because the data are assigned to the whole examined assembly area. All the above quality indices values are assessed as follows:

1. The ranking of all values in comparison to each other (best, second best and worst) is done.
2. Allocation of points to each status: The best gets 3 points, the second best gets 2 points and the worst gets 1 point.
3. Attach importance to each value: the most convincing values are the assembly *TC*; they get the highest weight and are multiplied by a factor of 3.
4. The best existing level of automation has the most points.

The results of the analysis show that the *Auto5000 GmbH* Wolfsburg manufactures are best according to all the quality indices. The second part of the task is to find the theoretical optimal automation level. Each Assembly Part which delivers the fewest trouble cases per vehicle,

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is investigated. These collected data are summarized in one theoretical optimal level of automation. The results of the analysis confirm the assumption that different fictitious levels of automation will create fewer defects and that a combination of automation levels will bring about a much better result than the existing methods.

D. *Productivity and Flexibility*

On the basis of the above described matrices, the productivity figures are examined in relation to the number of workers. These workers are later seen in relation to the vehicles built and the time needed for such. These relations are the indices of productivity taken into consideration in this analysis. The result of this analysis leads to the assumption that a highly automated method of manufacturing is also highly productive when taking into account that the smallest number of employees produces the highest number of vehicles as can be seen from the comparison shown in Fig. 3. On the other hand, the calculation of effectiveness shows that the availability of the high-automated production is susceptible to faults and trouble cases because of its complexity. On account of this, a high number of faultless units can only be reached when produced at a lower automated level, which includes the integration of highly skilled employees.

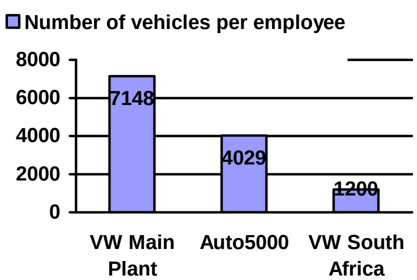

Fig. 3. Annual production quantities per employee

Flexibility of production equipment is difficult to quantify in financial terms. Also, product variations cannot be considered in this case since the automotive production equipment is specifically designed for a range of vehicle models. Nevertheless, the production equipment should have a sufficient capacity to accommodate a limited increase in production quantities. Therefore, in determining the levels of flexibility of Assembly Parts, the focus is on two aspects: the variation of production quantities and the number of workers required. From this point of view, the most flexible is the production system that has to change the least to cope with the increase/decrease of production quantities, i.e. a minimum variation in the number of workers. A variation of ±20% of production quantities was used in the analysis.

IV. Results and Discussion

The levels of automation of the assembly processes with regard to the three main aspects such as costs, quality and quantity are compared to obtain the optimal levels for each production site. If the different optima correspond with each other, the total optimum for the individual Assembly Part is already found. Otherwise, if the optima show differences in a certain Assembly Part, a further examination has 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 compared with the optimal level of costs to find a total solution for each production site. The results are shown in Table 6.

A. *Production of the Golf A5 model in Wolfsburg*

For Assembly Part 1, level 1 is the optimal automation level from a cost point of view, which represents actual assembling in practice. The productivity indices show the same optimum. However, the differences between the optimal level of costs and quality have to be remedied. The difference between the first and third level of automation from a quality point of view is 0.005 trouble cases per vehicle. A more detailed examination revealed that the assembly stations of roll forming of *tailgate* as well as roll forming of *doors* cause this difference. This is attributed to the robotic station, which allows only a very small tolerance for assembling. If this tolerance margin is not kept, the robot is not able to react appropriately, because an automatic station is not flexible enough to compensate for abrupt variances of tolerances. In order to achieve a better quality, 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 should be investigated.

Table 6. Optimal levels of automation

Index	***Golf A5* Wolfsburg**			***Touran* Wolfsburg**			***Golf A5* Uitenhage**		
	Assembly Parts								
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Cost	1	4	4	3	4	4	5	5	7
Quality	3	4	4	3	4	1	3	4	1
Productivity/Flexibility	1	2	4	2	3	4	4	4	6
Present Automation Level	1	1	1	4	4	4	5	5	7
Proposed Automation Level	**1**	**4**	**4**	**3**	**4**	**3**	**5**	**5**	**7**

For Assembly Part 2, the determination of the optimal level of costs and quality deliver the same level of automation as the optimal, which is level 4. However, the actual level of automation is level 1 and in productivity aspects, the levels 1 and 2 demonstrate the best options. However, level 4 shows a rising productivity with decreasing number of units. And, additionally, it provides a better flexibility because the operations are done manually and can be modified easily. Therefore, the actual level of automation in Assembly Part 2 has to be de-automated to reach the total optimal level but improvement of the quantity indices has to be considered.

For Assembly Part 3, the results of costs and quality are also the same, which is level 4. To reach an optimal

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quality level, the quality results have to be taken into closer consideration. The quality difference of 0.021 trouble cases per vehicle is caused by the assembly stations fitting a *battery* as well as fitting a *cross member* and a *rear bumper*. The assembly is performed automatically, whereas at other locations it is done manually with better quality results. However, for reaching a high quality performance in manual assembly, workers have to be adequately qualified, motivated and co-ordinated. The quantity aspect shows that level 1 and 4 provide the best flexibility. Level 1 also shows a better productivity. The other possibility is level 4, which is preferred from the point of view of costs and has the same flexibility as level 1, but provides better flexibility. In Assembly Part 3, the actual level of automation should be de-automated to reach the optimal level as well. The quality as well as the modifications in quantity should be kept in mind.

B. Production of the Touran model at Auto5000 GmbH

For Assembly Part 1, level 3 is the optimal level with regard to costs and also to quality, whereas the actual level of automation is level 4 in the *Auto5000 GmbH*. Regarding flexibility and productivity, level 1 is the optimal level for Assembly Part 1. Level 2 is only partly recommendable with respect to productivity because of its low level of flexibility. Assembly Part 1 should be automated to level 3.

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

For Assembly Part 3, the results of costs (level 4) and quality (level 1) do not correspond, which is the main concern. It appears that even with the highly extensive training programme which takes place at the *Auto5000 GmbH* plant, consistent quality is not possible without automation for this assembly process. Concerning productivity, levels 3 or 4 could be the optimum. Based on the results, Assembly Part 3 should be automated to level 3 to improve quality.

C. Production of the Golf A5 model in Uitenhage

In Assembly Part 1, the results of costs and quality differ from each other, but, in this case, it is exactly the opposite. The optimal level of automation regarding costs (level 5), is more de-automated than the optimal level of automation regarding quality (level 3). The above-mentioned argument that manual assembly is as good as automatic assembly or even better is not valid for the manufacturer in Uitenhage. Within the assembly of roll forming of *tailgate* and *doors*, differences with respect to quality occur again. These stations are implemented in exactly the same manner as in the manufacture of the *Auto5000 GmbH*, but they produce 0.101 more trouble cases per vehicle. This fact shows the deficiency of the *Golf A5* assembly in Uitenhage. 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. Assuming that quality will improve, level 5 can be seen as the optimum. This level is just a little less flexible than level 4. The advantage of level 5 is the higher productivity. The present method should be kept, improvements in quality are required.

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

Similar to the previous processes, the optimal automation levels of costs (level 7) and quality (level 1) differ for the same reason of low skills and/or poor motivation of workers. Quantitatively the levels 1 to 6 are all better than level 7. However, level 7 is the actual level of automation in South Africa. Level 7 is only partially recommendable with respect to quantity, because this level shows poorer values for flexibility and productivity compared with the other levels. The main advantage of level 7 is that it requires only basic equipment. Hence, the present method should be kept, with improvements in quality.

V. Acknowledgments

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