# RELATIONSHIP BETWEEN COMPLEXITY IN MANUAL ASSEMBLY WORK, ERGONOMICS AND ASSEMBLY QUALITY

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*Earlier studies have demonstrated strong relationships between manual assembly at high physical load levels and increased amounts of quality errors compared to assembly at low physical load levels. A recent Swedish interview study indicated that assembly complexity is also of importance for the assembly quality. The objective of this study was to examine the significance of complexity and the relationships between ergonomics, assembly complexity and quality by analyzing manual assembly tasks in car manufacturing. The results showed several significant correlations between ergonomics and assembly complexity, assembly time, failures and costs.*

*Keywords: Assembly, Ergonomics, Complexity, Quality, Failures*

## 1 Introduction

All manufacturers strive to produce and deliver as good a quality as possible. For competitive reasons it is important to achieve the best possible products at the lowest possible cost. As part of this, high assembly efficiency and delivery accuracy is required, which can be easily compromised by errors and disturbances during the manufacturing process. Today customers demand high product variety and short lead times and mass customization have been recognized as a new paradigm for manufacturing (Koren, 2006). As a consequence, assembly systems must be designed to be responsive to customer needs and at the same time achieve mass production quality and productivity. Rekiek et al. (2000) stated that in a typical automobile assembly plant, the number of different vehicles being assembled can reach ten thousands of combinations of build options. Such astronomical numbers of combination options present enormous difficulties in the design and operation of assembly systems. The question is how to design systems and organize production to allow high product variety without sacrificing quality and productivity. Assemblability (ease of assembly) has been defined as the ease of gripping, positioning and inserting parts in an assembly process (Fujimoto and Ahmed, 2001). Zhu et al. (2008) talk about the operator choice process or operator choice complexity, which means that for each assembly task, he/she must choose the correct part from all possible variants according to the customer´s order. For the operators in complex assembly systems there are many choices to make often under time pressure, such as e.g. picking the right material, the right tools, choosing the right method, making things in the right order etc. In paced assembly lines, cognitive and physical factors often put high demands on human performance, and as a result mistakes, quality deficiencies and other assembly related errors occur. Bishu and Drury (1988) found that the task completion time was linearly related to the amount of information contained in the task. Their results also showed that the more information gain there was, the more likely would errors occur. Zhu et al. (2008) concluded that in order to prevent this from happening, or at least reduce the problem it is important that system solutions, assembly solutions, material, methods and tools enable as flawless assembly as possible. Falck et al. (2010) concluded that defect products that require repair and exchange of parts and components can indeed be very costly for the company and they are more time-consuming and costly to repair the later they are found. Moreover, errors found by the customer affect the company´s reputation and may result in the customers choose another supplier the next time.

Many studies (e.g. Axelsson, 2000; Maudgalya et al., 2008; Generalis et al. 2007; Falck et al, 2010) have shown a clear relationship between ergonomics conditions and assembly related errors that affect the quality outcome of the products produced. A high physical load level in manual assembly results in more quality errors compared to low physical load level. In a recent study in Swedish manufacturing industry an interview of employees with lengthy experience in design and manufacturing engineering was made (Falck and Rosenqvist, 2012). The interview comprised questions about production ergonomics, complexity and assembly quality. The results indicated that in addition to ergonomics conditions the degree of complexity in manual assembly work was of great importance for the outcome of assembly quality and complex assembly tasks were said to result in more assembly errors than non-complex tasks. The respondents suggested a large number of criteria for high and low complex assembly tasks.

## 2 Objectives

The purpose of this study was to analyze the relationship between degrees of manual assembly complexity and assembly quality and compare these results with the quality results related to ergonomics load levels. As measure of the quality outcome the failure output and the cost for correction of manual assembly errors were used.

## 3 Methods

47 manual assembly tasks in an automobile industry in northern Europe were chosen for analysis: 16 at high ergonomics load level, 17 at moderate ergonomics load level and 14 at low ergonomics load level. A high load level (red) implies harmful impact on operators, moderate load level (yellow) implies moderate risk of harmful impact and low load level (green) implies none or very low impact on operators. (As numeric values the figures 3, 2, and 1, respectively, were used.) For 38 of the assembly tasks a cost analysis could be made that included 14 assembly tasks at high ergonomics load level; 14 tasks at moderate load level and 10 tasks at low load level. Examples of tasks were assembly of rear lights, inner rearview mirror, luggage side panels and front side door glasses. Selection and ergonomics assessment of tasks were made in cooperation with ergonomics specialist and responsible manufacturing engineers in the company. The selected tasks represented assembly tasks at various ergonomics load levels and assembly difficulty. Based on accurate assembly descriptions obtained from the manufacturing engineering departments, the degree of assembly complexity of all tasks was classified according to the specific assessment criteria presented by Falck and Rosenqvist (2012), see below. After complexity classification all 47 tasks were analyzed with respect to quality deficiencies. Further, for 38 assembly tasks the costs for correction of assembly related errors were recorded including also related warranty

and repair costs at dealers. The study used data stored in the logging databases in the company pertaining to a period of twelve weeks production. The average time for correction of errors were obtained by experienced team-leaders in the plant. These times were then used for calculation of the costs for corrective measures. A labor cost of 360 SEK/hour was used, which was obtained from the economy department in the plant.

An assessment scale (Table 1) for evaluating complexity of assembly tasks was developed based on the answers in the interview study by Falck and Rosenqvist (2012) suggesting criteria that characterize both low and high manual assembly complexity.

Criteria (n=16) for low assembly complexity (LC) tasks considered as “easy and fast” operations:

- Non-operator dependent operations not requiring much experience to be properly done
- Simple plug-in/ click-in solutions that are easy and quick to assemble
- No precision-demanding operations, “no fitting”
- Clear assembly order
- Few parts/components to mount; preassembly; module solution (integrated assembly)
- Few variants; standardized assembly that is the same every time
- Independence of assembly order (could only be done in one way)
- Self-evident operations that do not need written instructions
- Visible operations
- Clear mounting position of parts and components
- Easy fitting; self-positioning elements that can be controlled in three dimensions (x, y, z)
- Form-resistant material that do not change shape or form during assembly
- Immediate feedback of proper installation e.g. a click sound and/or compliance with reference points
- Good accessibility
- Good ergonomics conditions i.e. no harmful impact on operators
- No adjustment needed

Criteria (n=16) for high assembly complexity (HC) tasks considered as “tricky and demanding” operations:

- Many different ways of doing the task
- Many individual details and part operations
- Time demanding operations
- No clear mounting position of parts and components
- Poor accessibility
- Hidden operations
- Poor ergonomics conditions implying risk of harmful impact on operators
- Operator dependent operations requiring experience/knowledge to be properly done
- Operations must be done in a certain order
- Visual inspection of fitting and tolerances, i.e. subjective assessment of the quality results
- Accuracy/precision demanding
- Need of adjustment
- Geometric environment has a lot of variation (tolerances), i.e. level of fitting and adjustment vary between the products
- Need of clear work instructions
- Soft and flexible material
- Lack of (immediate) feedback of properly done work, e.g. a click sound and/or compliance with reference points

The degree of fulfillment of the criteria was used to design the scale for assessing complexity. For the scale five levels were chosen and designed with green, green-yellow, yellow, yellow-red and red. (As numeric values the figures 1, 1,5, 2, 2,5, and 3, respectively, were used.) Table 1 shows the degree of fulfillment of the low and high complexity criteria according to the bullet list above.

Table 1. Scale for assessment of complexity level and fulfillment of complexity criteria.

| Complexity level | Degree of complexity | Fulfillment of 16 LC criteria | Fulfillment of 16 HC criteria |
|---|---|---|---|
| Green | Low | 15-16 (94-100%) | 0-3 (0-19%) |
| Yellow-green | Rather low | 12-14 (75-88%) | 4-7 (44-25%) |
| Yellow | Moderate | 8-11 (50-69%) | 8-11 (50-69%) |
| Yellow-red | Rather high | 4-7 (44-25%) | 12-14 (75-88%) |
| Red | High | 0-3 (0-19%) | 15-16 (94-100%) |

The statistical analysis of relationships between different variables, ergonomics load level and complexity level, respectively, was built on ranked data. For this purpose, Spearman's rank correlation (SPSS) was used, which is based on ordinal scales.

## 4 Results

The study covered four different car variants that were built on paced assembly lines during a period of twelve weeks, in total 47 061 cars. The failures and amount of scrapped items were collected for all 47 assembly tasks. Table 2 shows that the failures for the red (high) complexity level was 2,8 times higher compared to the green (low) complexity level. However, the total number of failures and failures/task in the yellow-red (rather high) level was lower.

Table 2. Failures of 47 tasks distributed on five complexity levels.

| Complexity level | No. tasks | Total failures | Failures /task | Failures compared to green level | Average no. of failures /car |
|---|---|---|---|---|---|
| Green (low) | 14 | 1932 | 138 | 1,00 | 0,13 |
| Yellow-green (rather low) | 11 | 1651 | 150 | 1,09 | 0,14 |
| Yellow (moderate) | 9 | 1856 | 206 | 1,49 | 0,19 |
| Yellow-red (rather high) | 4 | 206 | 52 | 0,38 | 0,06 |
| Red (high) | 9 | 3505 | 389 | 2,80 | 0,44 |
| **All** | **47** | **9150** | **187** | | **0,19** |

Table 3 shows assembly related errors distributed on three ergonomics load levels. The results show that the green load level tasks have the lowest amount of failures/car and the red load level tasks the highest amount of errors. The red load level tasks had 5,9 times as many errors and the yellow load level had 3,7 times as many errors as the green load level tasks. But there were significant correlations at the 0,01 level (**) for total

Table 3. Failures of 47 tasks distributed on three ergonomics load levels.

| Ergonomics load level | No. tasks | Total no. of failures** | Distribution of failures, percentage | Average failures /task** | Failures compared to low load level | Average no. of failures /car** |
|---|---|---|---|---|---|---|
| Green (low) | 14 | 746 | 8,2 | 53 | 1,0 | 0,05 |
| Yellow (moderate) | 17 | 3359 | 36,7 | 198 | 3,7 | 0,22 |
| Red (high) | 16 | 5045 | 55,1 | 315 | 5,9 | 0,33 |
| **All** | **47** | **9150** | **100** | **195** | | **0,19** |

failures/task and failures/car. Additionally, the failures and action costs could be calculated for 38 of the assembly tasks associated with 26 219 of all 47 061 cars. Table 4 shows the failures and associated costs for corrective measures and scrap distributed on the five complexity levels. The results show that the total action costs, action costs/task and action costs/car increase with increasing complexity level with exception of the yellow-red tasks, where the total action costs were lower. The action costs/task and cost/car were significant at the 0,01 level (**). 1 SEK = 0,111 EUR.

Table 4. Failures and action costs of 38 tasks distributed on five complexity levels.

| **Complexity level** | **No. tasks** | **Total no. of failures** | **Failures /task** | **Total action costs (SEK)** | **Action cost/ task ** (SEK)** | **Average** action cost/ car (SEK)** |
|---|---|---|---|---|---|---|
| Green (low) | 11 | 819 | 75 | 45243 | 4113,00 | 5,52 |
| Yellow-green (rather low) | 8 | 1475 | 184 | 60886 | 7610,75 | 9,56 |
| Yellow (moderate) | 7 | 1722 | 246 | 59275 | 8467,86 | 10,94 |
| Yellow-red (rather high) | 4 | 206 | 52 | 50423 | 12605,75 | 27,29 |
| Red (high) | 8 | 1837 | 230 | 393903 | 49237,88 | 89,65 |
| **All** | **38** | **6059** | **159** | **609730** | **16045,53** | **23,26** |

In Table 5 failures and action costs for the three ergonomics load levels show that the failures/task is 2,6 and 4,0 times increased for the yellow and red load levels compared to green load level. However, the action costs/task and per car is higher for the yellow load level than for the red level but lowest for the green level. The failures/task was significant at the 0,01 level (**).

Table 5. Failures and action costs of 38 tasks distributed on three ergonomics levels.

| **Ergonomics load level** | **No. tasks** | **Total no. of failures** | **Failures/ task**** | **Failures compared to low load level** | **Total action costs (SEK)** | **Action cost /task (SEK)** | **Average action cost/car (SEK)** |
|---|---|---|---|---|---|---|---|
| Green (low) | 10 | 587 | 59 | 1,0 | 40071 | 4007,10 | 5,06 |
| Yellow (moderate) | 14 | 2136 | 153 | 2,6 | 380518 | 27179,86 | 44,66 |
| Red (high) | 14 | 3336 | 238 | 4,0 | 189141 | 13510,07 | 19,34 |
| **All** | **38** | **6059** | **159** | | **609730** | **16045,53** | **23,26** |

For the 47 tasks Spearman's correlation analysis was made for the relationships between ergonomics and assembly complexity, between assembly complexity and assembly time, between complexity and total failures and ergonomics and total failures. All showed significant correlation at the 0,01 level (**). The correlation between ergonomics, assembly time and costs, respectively was not significant.

## 5 Discussion

Since the correlation between ergonomics and assembly time was not significant, this means that assembly time is not of great importance for the failure output. Assembly complexity was significantly correlated to assembly time and action costs implying that complex assembly solutions should be avoided in order to avoid long assembly times and increased action costs. Assembly complexity and ergonomics showed significant relationships and it could be expected that ergonomics should be significantly correlated to assembly time and costs but was not. Ergonomics (but not complexity) showed a significant correlation with failures /task. Yet, assembly complexity and total action costs and costs/assembly task showed significant correlations. Presumably, a large amount of failures and high action costs of single tasks (as in the yellow level in in Table 2, 4 and 5) influenced the results due to a relative low total number of assembly tasks despite the large number of cars that were studied. Besides, the yellow level tasks might have been too low risk classified A larger number of tasks might have equalized this, which ought to be further analyzed in future studies.

## 6 Conclusion

Complex assembly tasks result in higher action costs. Assembly time related to ergonomics load level is of little importance for the failure output. Ergonomics and complexity factors are interrelated but in what respect could not be decided. What complexity factors, which are most important for failure output and action costs is not possible to tell but must be further elaborated.

To increase assembly efficiency and quality, assembly at high ergonomics load level and high complexity level should not be accepted.

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