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Procedia CIRP 44 (2016) 424 – 428

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6th CIRP Conference on Assembly Technologies and Systems (CATS)

Criteria for assessment of basic manual assembly complexity

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Abstract

Tough competition force companies to develop and increase their product assortment in order to maintain their market share. This has resulted in numerous product variants with more features and build options. The complexity and risk of quality errors will increase. Managing complex product and installation conditions will result in distinct competitive advantages. Research has shown that sustainable and more cost-efficient assembly solutions can be obtained by proactive improvement of the working environment and installation conditions for the operators. Significant reduction of costly corrective measures can be made. The objective of this paper was to demonstrate criteria for proactive assessment of manual assembly complexity, which have been developed and verified in several studies. A further objective was to clarify and quantify included criteria as far as possible to enable a more general application in manual mass production of complex products.

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)

Keywords: Assessment; Basic complexity criteria; Manual assembly complexity; Quality; Error; Cost

1. Introduction

Increased competition for customers in the international market have forced manufacturing companies to increase and diversify their product range. This has led to numerous product variants and build options such as in the automotive industry. In a typical assembly plant the numbers of different vehicles, variants and options can thus reach numerous combinations of build options. A huge amount of variants and build options is a major challenge in production planning and for the operator who is supposed to manage many different assembly tasks in paced assembly lines. There are many choices to make often under time pressure, e.g. pick the right material, the right tools and make things in the right order etc. [1]. As a result cognitive and physical factors often put high demands on human performance, which cause mistakes, quality deficiencies and other assembly-related errors. There is a clear relationship between task variables and perceived assembly difficulty [2] and the more assembly options that are available to the operator, the more assembly-related errors are likely to occur [1]. Decisions taken during early design phases of product and production development have been found to have a major impact on assembly conditions in automotive manufacturing [3]. The higher the degree of basic assembly complexity the higher were the reactive action costs for correction of assembly-related quality errors. A big part of the quality errors were due to loose parts, parts in wrong position or wrong fitting, which was considered to be geometry-related errors. For those reasons, a model for geometrical robustness analysis considering manual assembly complexity was developed [4]. However, the assembly complexity criteria used need to be further described in order to facilitate application.

Nomenclature

Basic manual assembly complexity includes the basic design of products, components and system solutions developed and decided in early design phases. Basic assembly complexity includes both physical and cognitive factors.
HC: High manual assembly complexity
LC: Low manual assembly complexity

Peer-review under responsibility of the organizing committee of the 6th CIRP Conference on Assembly Technologies and Systems (CATS)
doi:10.1016/j.procir.2016.02.152

TMU: Time Measurement Unit: 1/26th of a second

1.1. *Assessment of assembly complexity*

Several attempts have been made to comprehensively explore the meaning of the complexity concept in design and manufacturing context [e.g. 1, 5, 6, 7, 8 and 9].Very few studies of complexity impact on assembly quality have to date been made in current production context. However, researchers [6] identified seven task variables for prediction of object assembly difficulty that was based on operators´ view. Further studies [10, 11 and 12] focused on assembly complexity as perceived by operators and individual operator factors in order to support operators *at station level* in building the right quality in mixed-model assembly lines. Another study [3] in the automotive industry had a different approach focusing on how *basic* manual assembly complexity affected operator performance, assembly quality and productivity. The results clearly showed that the higher the complexity level the higher were the reactive action costs in manufacturing due to assembly-related errors and scrapped parts and components. The criteria used for assessing assembly complexity were obtained from an earlier interview study [13] with very experienced engineers in design, manufacturing engineering and production development in Swedish manufacturing companies. Based on their answers about high and low assembly complexity sixteen criteria characterizing high manual complexity and sixteen criteria characterizing low manual complexity were identified. In this paper the criteria of both high and low assembly complexity are shortly presented and the procedure for complexity assessment is described.

1.2. Objective

The objective of this paper is to concisely present method criteria for predictive assessment of manual assembly complexity. A more detailed method description will be published elsewhere. The overall objective is to prevent costly assembly-related errors and create sustainable manufacturing conditions in early concept phases of new manufacturing solutions.

2. Criteria description and assessment approach

There are sixteen criteria for high manual assembly complexity (HC) and sixteen criteria that characterize low manual assembly complexity (LC). The HC criteria could be considered as “tricky and demanding” and the LC criteria as “easy and fast”. These criteria are intended for assessment of individual assembly tasks or elements. All criteria should always be assessed for each assembly task and each criterion must be *either* HC *or* LC. For example when criterion **4** is to be assessed it must be decided if the task conditions complies with **No clear mounting position of parts and components** meaning **HC** or ***Clear mounting position of parts and components*** meaning ***LC* .** After assessment of all HC and LC criteria the results could be for instance nine LC and seven HC or three HC and thirteen LC criteria. The HC and LC criteria are not meant to be each other´s opposite but function as control questions for improved assessment of each assembly task. This approach aims at identifying potential assembly difficulties in early development stages of product and assembly concepts when it is still possible to change to other solutions.

The information required in basic complexity assessment is an assembly task or operation description of how the work should be performed, with what components and parts, with what tools and equipment and how long time the work is expected to take.

2.1. Checklist for evaluation of basic manual assembly complexity of assembly tasks.

A checklist is being developed and tested for evaluation of assembly tasks according to the HC and LC criteria below. The filled in checklist will illustrate which of the criteria that are problematic and which are not for each assembly task. Filled in HC criteria will require actions in order to remove risks of poor quality. The goal is to reduce the number of met HC criteria and increase the number of LC solutions in order to ensure as flawless assembly as possible. The complexity criteria are intended to be used by engineers in manufacturing engineering for identification of potential quality issues in development of assembly solutions.

2.2. Sixteen HC and sixteen LC criteria

1. **HC: Many different ways of doing the task.**
LC: Standardized (accepted) way to do the task.

Interpretation/Evaluation: Is it possible to assemble the parts/perform the task in different ways for instance with or without hand tools? If yes: The complexity is high (HC); If no: The complexity is low (LC).

2. **HC: Many individual details and part operations.** ***LC: Few parts/components to mount; preassembly; module solution (integrated assembly).***

Interpretation/evaluation: There is a difference between details and part operations. Both have to be taken into account: The number of part operations (normally described in the operation description) and individual details should be counted separately. (Note that some operation descriptions may be split up on several stations).

Clarification: Individual details (ID)**:** All parts to be mounted/fastened should be counted. However, pre-mounted details should *not* be counted and included. Example: 4 screws = 4 details but (built-in) reference pins should not be included because these were already mounted.

Part operations (PO)**:** All operations that consume /assembly/ time (TMU, sec. or other time units) should be counted.

The limit values should be calculated based on the average number of details and sub-operations of a large number of task instructions as shown in the example from car manufacturing:
Low amount of ID + PO (0-6): Low complexity = LC
High amount of ID + PO (7<): High complexity = HC

3. HC: Time demanding operations.

LC: Solutions that are easy and quick to assemble (non-time demanding).

Interpretation/Evaluation: The evaluation of this criterion depends on the combinations of different operations at the same time. The median assembly time of the longest part operation of many operations was used as limit value.

Clarification: For each /assembly/ task the following steps should be made:

- See what part operation in the task description has the longest /assembly/ time?
- Make a median value from the longest time (TMU; seconds; other) of all operation descriptions.
- All tasks with an operation time longer than the median time => time demanding operation (HC).

4. **HC: No clear mounting position of parts and components.**
   LC: Clear mounting position of parts and components.

Interpretation/Evaluation: If the following current parameters are not fulfilled in *every part* operation and component, the task should be assessed as HC. Note that the following terms are used in the Swedish automotive industry:

- Guiding/controlling
- Reference systems
- Reference pins
- Fixtures
- Clips/screws
- Latches
- Controlling spline
- Rotation stop
- Snaps/hooks
- T-studs (integrated reference system)
- Tracks/cuts

5. **HC: Poor accessibility.**
   ***LC:* Good accessibility.**

Interpretation/Evaluation: Poor accessibility means insufficient access for hands/hands + tool and/or whole body or body part. If there is no good accessibility the task should be assessed as HC. Note that this criterion is *either* assessed stand-alone *or* included in the ergonomics assessment (no. 7).

6. **HC: Hidden operations.**
   LC: Visible operations.

Interpretation/evaluation: If the place where the part is to be mounted is *not* in the field of view when directly looking at the car or assembly location, the operation is HC; if clearly visible the operation is LC.

7. **HC: Poor ergonomics conditions implying risk of harmful impact on operators.**
   LC: Good ergonomics conditions implying no harmful impact on operators.

Interpretation/evaluation: Ergonomics is regulated by Swedish law and EU directives. In assessment an established ergonomics requirement specification, checklist or standard should be used.

8. **HC: Operator dependent task requiring expert knowledge to be properly done.**
   LC: Non-operator dependent operations not requiring much experience to be properly done.

Interpretation/evaluation: If either of the questions below are fulfilled the criterion should be assessed as HC:

- Is there any additional training/practicing necessary (expert knowledge) beyond common introductory sessions?
- Is this a station where the newly employed could be placed after the introductory session?

9. **HC: Operations must be done in a certain order/sequence.**
   LC: Independence of assembly order.

Interpretation/evaluation: The HC **c**riterion is fulfilled if you have to follow a certain order, otherwise it is not possible to assemble/perform the task correctly. If it does not matter, it is LC.

Clarification: If it is important to follow the operation description exactly and if it specifies in detail how the task should be performed and where to start the operation the complexity is high (HC) such as regarding the text: ”Fasten the part with four screws, begin with the top right corner, then continue with the bottom left corner”. This in order to avoid other ways that may jeopardize the quality. If the tasks is simple, intuitive and can be performed in just one way, the complexity is low (LC). (Compare criterion 1.)

10. **HC: Visual inspection of fitting and tolerances is required, i.e. careful subjective assessment of the quality output.**
    LC: Careful subjective assessment of fitting/tolerances is not needed.

Interpretation/evaluation: If subjective assessment (e.g. feel if..) or visual inspection (see if..) is explicitly stated (in the operation description) in order to secure good quality after the task is done, then the task means HC.

11. **HC: Accuracy/precision demanding task.**
    LC: No precision-demanding task, no careful fitting is necessary.

Interpretation/evaluation: If there are particularly high demands on fine motor skills of the operator or very precision demanding work like fitting a detail within millimeters or assembly with long distance to the detail, then the operation should be considered as HC. Often this kind of task results in bad working postures due to high vision demands.

12. **HC: Need of adjustment.**
    LC: No adjustment needed.

Interpretation/evaluation: Need of adjustment of the task refers to the specific station where the work is performed. A need of adjustment often depends on how frequent errors occur. If adjustment is frequently needed due to product or component design or because things easily go wrong, then the task should be considered as HC.

13. HC: The geometric environment has a lot of variation (tolerances) meaning the level of fitting and adjustment varies between the products.
LC: Easy fitting, self-positioning parts/components that can be controlled in three dimensions: X, Y, Z.

Interpretation/evaluation: If the surrounding environment varies, where parts and components things are going to be mounted or if the detail to be positioned is dependent on the surrounding components, then the HC criterion is met. Examples of when the geometric environment has great variety are: Several holes have to overlap; components that are not joined; components are moving relative to each other. If there is a fixture, the HC criterion is not met because the purpose of the fixture is to remove the influencing surrounding environment = LC.

If measured tolerances are close to or outside predetermined limits there is a risk that parts/components will not fit properly or will be difficult or impossible to position. As a result poor quality or function will occur. This criterion should then be assessed as HC as well as when the tolerances are outside the limits.

14. HC: Need to have in detail described work instructions.
LC: Self-evident operations that do not need clearly written instructions.

Interpretation/evaluation: Is there a risk of errors or poor quality if the work instructions are not accurately followed, then this criterion should be assessed as HC. Errors/poor quality will result in a need of adjustment and/or scrap. Questions that should be asked are (See also criterion 9 and 12):

- In what order are components going to be assembled?
- How is the assembly going to be done?
- With what tools/components?

15. HC: Soft and flexible material.
LC: Form-resistant material that do not change shape or form during assembly.

Interpretation/evaluation: The following examples of material considered as soft and flexible are often difficult to position geometrically correct because they behave in a poorly controlled manner (see also criterion 13.):

- Rubber strips and rubber plugs
- Cables and wires
- Carpets
- Some panels and covering material (e.g.: door panels, interior panels)
- Safety belts
- Tubes and hoses
- Tottering material/parts/components

16. HC: Lack of immediate feedback of properly done work, e.g. by a click sound and/or compliance with reference points.
LC: Immediate feedback of proper installation by a click sound or compliance with reference points.

Interpretation/evaluation: All part-operations have to give immediate feedback including screw joints to be assessed as LC. Otherwise some risk is remaining = HC. This criterion is closely related to criterion 10.

3. Discussion

Assessment of complexity criteria is not always smooth because every criterion has to be put into a context, which may vary in different manufacturing conditions. In rebalancing or change of the work contents of work stations the assembly conditions may change for the better or for the worse for the operators. A split-up of tasks on several stations and change of mix in mixed model assembly lines could affect the basic assembly complexity. This type of transformation cannot be predicted in detail before start of production but must also be considered with respect to operator performance and quality outcomes. However, the aim of this paper was to present basic assembly complexity criteria for prevention of assembly-related quality-errors in design and manufacturing engineering.

Some of the complexity criteria seem very similar but still differ and have therefore not been merged. Criterion one and nine look similar but criterion one considers the possibility of doing the task in different ways with or without available tools (lifting equipment, hand tools and other equipment) or in the wrong place due to accelerated work. In order to save time operators often "invent" their own ways of doing a task, which could impact the quality. Criterion nine instead refers to the order in which each step of the assembly task is done. Criterion ten and sixteen do not assess the same thing. Criterion ten concerning visual inspection of fitting and tolerances is sometimes necessary if there is no clear feedback of properly done work especially when there are unclear reference points such as with soft and flexible material and inspection of dirt on surfaces and material damages. Criterion sixteen considers tasks that should provide an immediate feedback.

The complexity criteria have not been given different weight because the research results have not clearly demonstrated which criteria that are more important than others. Therefore, all criteria should always be assessed. Ignoring criteria that seem less problematic for the moment is risky because if so they might start to cause problems again in the future.

Assessment of criterion 2 and 3 and their limit values may vary depending on the manufacturing context. What number of details, part operations and assembly time that should be considered as HC or LC cannot be generalized for all manufacturing but should be decided based on the risk for errors and quality problems in the specific case.

The complexity criteria were developed to enable assessment of manual assembly complexity in early design and development phases of new products and system solutions including installation concepts in the automotive industry. However, the complexity criteria should be applied more generally in manual mass production of complex products.

4. Conclusions

The most efficient way is to make complexity assessments as early as possible in product development before start of production while design changes are still possible. The later assessments are made the more difficult changes and improvements will be and the costs for design changes are also most likely to increase. In assessing the degree of assembly complexity of each work task it is useful to have both the low and the high complexity criteria available. The goal is to reduce the number of high complexity criteria and meet the low complexity criteria as far as possible. If not every LC criterion is fulfilled, then quality risks still remain that require action. The complexity criteria presented in this paper are not necessarily a complete list of all existing criteria although they were obtained from various manufacturing industries.

Acknowledgements

This work was carried out at the Wingquist Laboratory VINN Excellence Centre within the Area of Advance - Production at Chalmers University of Technology in Gothenburg, Sweden, supported by the Swedish Governmental Agency for Innovation Systems (VINNOVA). The support is gratefully acknowledged. Furthermore, the authors acknowledge the financial support provided by 'Fordonsstrategisk Forskning och Innovation' (FFI).

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