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Assembly failures and action cost in relation to complexity level and assembly ergonomics in manual assembly (part 2)

Ann-Christine Falck*, Roland Örtengren, Mikael Rosenqvist

Department of Product and Production Development, Chalmers University of Technology, SE-41269 Göteborg, Sweden

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A B S T R A C T

Earlier studies have demonstrated strong relationships between manual assembly at high physical load levels and increased amounts of quality defects compared to assembly at low physical load levels. A recent Swedish interview study of engineers in design and manufacturing engineering indicated that assembly complexity factors are of additional importance for the assembly quality. The objective of this study was therefore to examine the significance of high and low complexity criteria and the relationships between assembly ergonomics and assembly complexity and quality failures by analyzing manual assembly tasks in car manufacturing. In total, 47 000 cars were analyzed and the results showed several significant correlations between assembly ergonomics and assembly complexity, assembly time, failures and action costs. The action costs for high complexity tasks were 22.4 times increased per task per car compared to low complexity tasks.

Relevance to industry: Assembly ergonomics and assembly complexity factors interact. Both should be proactively considered in order to keep assembly-related failures and action costs as low as possible.

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 failures 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, the operator 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, 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 failures occur. Bishu and Drury (1988) found that the more information gain there was, the more likely would failures occur. Zhu et al. (2008) concluded that in order to prevent this from happening, or at least reduce the risks, 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 that they are more time-consuming and costly to repair the later they are found. Moreover, failures found by the customer affect the company's reputation and may make the customers to choose another supplier the next time.

Many studies (e.g. Axelsson, 2000; Maudgalya et al., 2008; Generalis and Mylonakis, 2007; Falck et al., 2010) have shown a clear relationship between assembly ergonomics conditions and

* Corresponding author. Tel.: +46 707 832109.
E-mail addresses: annchrif@chalmers.se, afalck@telia.com (A.-C. Falck).

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assembly-related failures that affect the quality outcomes of the products produced. A high physical load level in manual assembly results in more quality defects compared to a low physical load level. In a recent study in Swedish manufacturing industry an interview of 64 employees with lengthy experience in design and manufacturing engineering was made (Falck and Rosenqvist, 2012). The interview comprised questions about assembly 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 failures than non-complex tasks. Based on their lengthy professional experience the respondents suggested a large number of criteria for both high and low assembly complexity.

2. Objectives

The purpose of this study was to analyze the relationship between manual assembly complexity and failure rate and action costs and compare these results with failure rate and action costs related to ergonomics load levels. Another purpose was to see if there was any relationship between assembly ergonomics and assembly complexity. As measure of the quality outcomes the number of assembly-related failures and the costs for correction of these failures were used.

3. Methods

This study was carried out in an automotive company in northern Europe and included assembly-related failures in manual assembly of cars. The number of failures, scrapped parts, components and costs for corrective measures were collected for both the Final assembly and the customer's market. All quality data was collected and analyzed retrospectively pertaining to a period of twelve weeks production. When necessary, additional information was obtained from responsible team leaders, quality engineers and managers to ensure that the correct data was collected.

3.1. Delimitations

Only assembly-related failures in manual assembly were analyzed. Supplier-related quality failures and material failures were excluded. In this paper ergonomics refers only to assembly (load) ergonomics.

3.2. Choice of assembly tasks and methods for tracking failures

Initially 54 assembly tasks were selected for analysis. Examples of tasks are assembly of rear lights, inner rearview mirror, luggage side panels and front side door glasses. Selection and assessment of the tasks was made in cooperation with the responsible ergonomics specialists and the manufacturing engineers in the company. The selected tasks were assessed with respect to assembly complexity according to 16 high complexity (HC) criteria that were the results from the interview study by Falck and Rosenqvist (2012) (see below). Since the interview answers in the study indicated that there could be an overlapping relationship between assembly complexity and assembly ergonomics the assembly tasks were also assessed according to company specific assessment criteria for load ergonomics (VCC, 2010) and the Swedish regulation for load ergonomics (AFS, 1998).

The ergonomics assessment criteria used cover work load, work movements, work posture, tooling and material handling/packaging. These main factors include the following sub-criteria:

- *Work load*:

Manual lifting and carrying considering weight/force, lifting frequency and lifting distance; center of gravity of handled objects, seizability (difficulty of grasping) and other heavy handling such as push and pull forces (e.g. handling suspension devices); static load, working capacity (pulse frequency).

- *Work movements*:

Work movements/body part considering flexion-extension, bending and rotation of the neck, shoulder, elbow, wrist and finger joints; back, hip, knee, ankle and toe joints; time and frequency/movement, presence of monotonous repetitive work, precision and power in combination, pressure/insertion forces and body movement (e.g. climbing in and out of cars and up and down stairs).

- *Work posture*:

Considering working height (e.g. work above shoulder height or below knee height), working distance, handgrip (over/underhand gripping), pressure forces, clearance of hand/arm/whole body; hip/knee load and vision requirements.

- *Tooling:*

Considering handheld tools/machines, handling of lifting devices and other facilities used such as knives, screwdrivers and pliers etc.

- *Material handling/Packaging:*

Considering layout and packaging of feed materials; accessibility and manageability with respect to weight, gripping (difficulty of grasping) and work postures involved in material picking.

All assembly tasks in the study were assessed according to the prescribed limit values and guidelines belonging to the criteria listed above and thereafter classified into three physical load levels. Work tasks that were classified as high ergonomics (physical) load level (red) are: e.g. static work in forward bent work postures with the back bent more than 60° or the shoulders elevated more than 60°; repetitive work with the arms/hands above head level and the neck bent backwards; repetitive high push forces of the wrists. Work tasks that meant varied physical load near neutral positions of the body parts (e.g. work in upright position with only slight bending/twisting of body parts and low forces/weights (below stipulated limit values) were classified as low load level (green). Moderate load level (yellow) meant work tasks that were neither high (red) nor low (green) level, e.g. moderate side bending of the neck (below 30°) and moderate forward bending of the back (below 60°). The aim of the level of the assessment requirements are to prevent work-related musculoskeletal disorders as far as possible and to attain good quality of the work performed. For these reasons the levels of the requirements are designed to fit both men and women, young and elderly employees.

Table 1
Scale for assessment of complexity level and fulfillment of high complexity (HC) criteria.

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