The influence of assembly ergonomics on product quality and productivity in car manufacturing – a cost-benefit approach

Falck, Annki[a,*], Örtengren, Roland[a], Högberg, Dan[b]

[a] Department of Product and Production Development, Chalmers University of Technology, SE-41296 Göteborg, Sweden.
[b] School of Technology and Society, University of Skövde, SE-54128 Skövde, Sweden.

Abstract

Car manufacturing is often associated with poor working environment resulting in musculoskeletal disorders and high sick leave among assembly workers. Besides, a number of studies have proven that there is a clear correlation between assembly ergonomics and product quality and that poor assembly ergonomics result in impaired product quality and in decreased productivity. Many proactive measures have been made trying to prevent these problems such as training production staff in load ergonomics, workstation improvements, work rotation and design changes in product and production development. Nevertheless, there are remaining difficulties in receiving acceptance for changes of product and production solutions that cause poor assembly ergonomics.

This project aims at analyzing the relation between assembly ergonomics, assemblability and product quality. The objective is to quantify ergonomics and assemblability in economic terms in order to better support the development of more ergonomic product and assembly solutions, particularly at early stages of the car development process. Overall, the purpose is to create a tool that supports decision making in the design of assembly concepts. The tool will have functionality to assess ergonomic conditions in terms of quality and productivity, interpreted in monetary terms.

A selection of assemblies of high, medium and low physical work load are followed and evaluated with respect to quality errors for eight weeks in production. The numbers of quality errors are registered and the costs for scrap and corrective quality actions are calculated. For each ergonomic risk level the purpose is to define an associated quality cost.

Keywords: ergonomics, quality impact, productivity

1. Introduction

Early proactive ergonomics during manufacturing engineering of new car models is rather common in car manufacturing today. This is because late changes to the work and the workplace design are very costly and not always possible. In early design phases of new products and in production planning, changes are less costly and easier to make. For that reason many European and American automobile manufacturers use digital human modelling tools (DHM)[1] for evaluation of physical work load and for detection of ergonomics risks, i.e. Ford North America, Jaguar, Land Rover, Volvo Car Corporation and SAAB Automobile (Falck, 2002; Bäckstrand et al., 2005; Stephens and Godin, 2006). In the automotive industry

[1] DHM: A model of the work station is built-up in the computer and a virtual operator (a computer manikin) performs the planned work tasks. The simulated assembly sequence is then analyzed with respect to i.e. work load and work postures.

* Corresponding author. Tel.: +46 31 7721271; 0707 508976; e-mail: annchrif@chalmers.se

simulations with computer manikins are frequently used to predict ergonomics issues before the product and work place exist physically (Chaffin, 2001; Lämkull, 2006). There are two main purposes of ergonomics simulations: firstly to convince design engineers to change or modify the design of the product in order to improve the ergonomic conditions at work and secondly to guarantee a better product quality through improved assemblability.

Design engineers often do not recognize the consequences of a poorly designed product and work station due to lack of ergonomics competence and time (Broberg, 1997). A major problem in early proactive work is that the positive effects are not seen until several years later. Eklund (1999) showed in a study in Swedish automotive industry that 60 – 70% of the musculoskeletal disorders are caused by the product design and 30 – 40% by the production process. Long-term experience at Ford North America, Volvo Car Corporation and SAAB Automobile indicates a similar relationship. Both Eklund and Axelsson (2000) identify a strong correlation between ergonomics and product quality. Poor ergonomics conditions such as poor visibility, poor working postures and high assembly forces undoubtedly cause quality deficiencies of the product. The research by Eklund and Axelsson demonstrates that work under poor ergonomic conditions typically result in three to ten times as many quality defects in comparison with appropriate working conditions.

For competitive reasons in the automotive industry, great efforts are set on optimal cost-efficient product solutions in the design and manufacturing engineering process. The tough profitability demands on a limited time basis can thus make it hard to achieve acceptance for an ergonomically improved but initially more costly solution. Yet a number of studies have shown that product design or redesign, workplace ergonomics and safety initiatives result in remarkable increase in productivity, quality, safety records and in cost benefits. In some studies it took only eight months to obtain a payback in terms of monetary investment in the safety initiative (Hendrick, 1996; Maudgalya et al., 2008). The fact that a number of studies have demonstrated how poor ergonomics result in deteriorated quality and therefore increased production costs over time (Gröjer and Liukkonen, 1990; Oxenburgh et al., 2004; OSHA, 2008) is unfortunately not always sufficient in the specific case. Nor are references to ergonomics requirements and legal demands. Instead, a cost- benefit analysis will often be required (Bäckstrand et al., 2005). However, such a requirement represents a challenge since the costs for productivity losses and product errors caused by poor assembly ergonomics are additional (“hidden”) costs and often not known by most managers (Oxenburg and Marlow, 2005). Besides, reliable cost calculations will require adequate and detailed company data.

1.1. Research questions

The purpose of this study is to quantify the quality problems related to poor ergonomics and assemblability in economic terms in order to better support ergonomic product and assembly solutions during the early development process of new car models. To enable this, a number of research questions need to be answered:

- Can product solutions related to poor ergonomics be identified:

  a) in the quality assurance systems?
  b) in the manufacturing engineering process?
  c) in the assembly process?

- To what degree is there a correlation between poor assembly ergonomics and quality problems?

- To what extent do assembly ergonomics influence the product quality - at high, medium and low physical load level[2] ?

- What are the costs for quality problems caused by poor assembly ergonomics?

In this paper, before the collection of data is finalized, it is not yet possible to present the full answers to the research questions above. These answers will be presented in forthcoming papers after the collection of data have been finalized and analyzed.

2. Method

This study is carried out in an automotive company where the investigation begins in manufacturing engineering and continues in the assembly plant until the cars are factory complete. In the late project phases, three new car models close to plant launch (start-up of production) are chosen for analysis. All ergonomics and quality problems identified in new car projects are logged in a Product Verification System (PVS) in use by the manufacturing engineering department (Figure 1). The manufacturing engineers are responsible for identification of and solving both the ergonomics and the quality matters in projects. The project ergonomists are contributing with specialist competence and are responsible for having a holistic view of the ergonomics status in each project.

First, a comparison of ergonomics and quality problems identified by manufacturing engineers and project ergonomists is made. The objective is to see to what degree there is an agreement between the listed ergonomics problems and the listed quality problems of the product (Table 1). Then, from the PVS lists, a selection of 58 assembly items for ergonomics and quality evaluation is made in cooperation with the company ergonomists. Thus, 19 assemblies at high load level, 18 assemblies at medium load level and another 21 assemblies at low load level are chosen for evaluation. During eight weeks in production the number of quality errors per assembly is recorded continuously for all three production shifts. For the current evaluation the plant system for tracking and feedback of quality errors to the assembly teams (Atacq) is used.

Another system, the audit for weekly random sampling of factory complete cars (G-FCPA) completes the input from Atacq. In addition, input from a local plant system used for blocking factory complete cars with severe faults (TRACY) is also evaluated with respect to quality errors related to ergonomics. Simultaneously, the number and costs for scrap material, exchange of parts and repair are collected for the same period of investigation through the material coordinators in the assembly shop. Supplier related quality errors are not included in the collection, and only quality errors caused in the assembly plant are collected.

3. Results

In total, 55 assembly items were evaluated during eight weeks: 19 assembly items at high ergonomics risk, 17 items at medium risk and 19 items at low risk. Of the originally 58 selected assembly items for evaluation, three were excluded. Two items were excluded due to a mixture of faults mostly caused by insufficient quality delivery from suppliers.

2

High load (risk) level = high physical stress with harmful effect of work on the body. The load level is also called red.
Medium load (risk) level = moderate physical stress with potential harmful effect on the body if work is performed for longer periods. The load level is also called yellow.
Low load (risk) level = low physical stress with minimal risk of harmful effect of work on the body. The load level is also called green.

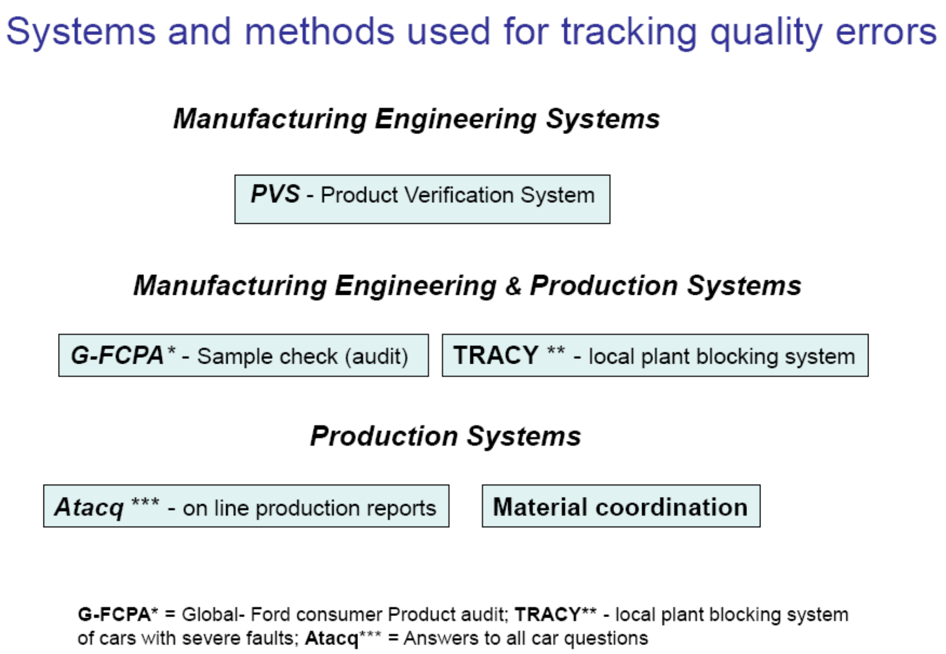

Figure 1. Company systems for quality assurance used for tracking quality errors connected to poor ergonomics and assemblability in manufacturing engineering and in assembly.

Table 1. Summary of research purposes, evaluation methods and point of time.

No.	Purpose	Method	Time
1	Investigate if /to what degree ergonomics problems are recorded as quality issues during manufacturing engineering.	Product Verification System (PVS)	Before launch of production
2	Selection of a number of ergonomics problems of high risk (n =19), medium risk (n =18), and low risk (n =21). In total 58 problems are selected for evaluation.	Selection of ergonomics problems in cooperation with company ergonomists	Before launch of production
3	Follow and evaluate 58 assembly items during eight weeks in production.	Gather data from Atacq, G-FCPA and TRACY.	During production in the plant
4	Map the costs for corrective measures and scrap in production.	Data from internal company sources and interviews of staff	In production
5	Calculate the total quality costs per ergonomics problem.	Calculation of quality cost related to ergonomics	End of study
6	Develop a tool that supports decision making in the design of new assembly concepts.	A calculation model for cost-benefit analysis of ergonomics	
7	Conclusions and recommendations.		

The two items are the headlining module assembly (low risk) and the overhead console assembly (medium risk). The third item, fuel filling (low risk), was excluded due to circumstances that the assembly operators could not influence during direct assembly.

When comparing the logged quality issues with assemblies at high ergonomics risk in the Product Verification System, it was found that these agreed to some extent. Furthermore, almost all of the early identified ergonomics assembly items of high and medium risk were found again in production and causing quality errors as tracked in Atacq.

In the audit system for weekly random sampling of factory complete cars (G-FCPA), 216 cars were completely analyzed by the quality engineers during the research period of eight weeks. For these cars 47 quality errors related to the selected assembly items were discovered, on average 5, 9 errors per week. 46 errors were related to assemblies with high and medium load level, one error was related to low physical load level. In the system for blocking factory complete cars (TRACY), a number of cars are found with quality errors related to the selected assembly items. However, since there is a delay of report of the total numbers and costs, this data is not yet fully available for evaluation.

For product safety reasons three assemblies were surveyed by a quality assurance system in order to certify that every screw was assembled with the right torque. This highly sensitive system automatically recorded errors, which resulted in a large number of quality remarks in Atacq. For that reason the figures shown in table 2 below are made both including and excluding these automatically recorded errors:

Table 2. Number of quality errors in Atacq and G-FCPA per assembly with high/medium/low load level. The figures displayed are before/after exclusion of automatically recorded quality errors.

<table>
<tr><th>Ergonomics load (risk) level</th><th>No. of assem blies</th><th colspan="2">No. of quality errors</th><th colspan="2">% share</th><th colspan="2">Increased risk factor for quality errors compared to low load level</th></tr>
<tr><td>High (red)</td><td>19 / 18</td><td>5092 / 4993</td><td rowspan="2">10385 / 7950</td><td>43% / 56%</td><td rowspan="2">87% / 89%</td><td>3.4 / 5.2</td><td rowspan="2">6.9 / 8.3 times</td></tr>
<tr><td>Medium (yellow)</td><td>17 / 16</td><td>5293 / 2957</td><td>44% / 33%</td><td>3.5 / 3.1</td></tr>
<tr><td>Low (green)</td><td>19 / 18</td><td colspan="2">1504 / 962</td><td colspan="2">13% / 11%</td><td colspan="2"></td></tr>
<tr><td>Total:</td><td>55 / 52</td><td colspan="2">11889 / 8912</td><td colspan="2">100% / 100%</td><td colspan="2"></td></tr>
</table>

The assemblies with high load levels resulted in 3.4 times more quality errors compared with the assemblies with low load level *before* exclusion of automatically reported errors and 5.2 times *after* exclusion. The assemblies with medium load level resulted in corresponding values of 3.5 times *before* exclusion of automatic registration and 3.1 times *after* exclusion. When merged, the increased risk for quality errors is 6.9 times 8.3 times respectively.

4. Discussion

To be able to perform a prospective and penetrating study like this, access to and knowledge about many company specific systems and information is required. In order to choose the right tools and to achieve the correct information, thorough familiarity with the industrial system, the work organization and the company structure is required. A great number of contacts at all levels in the organization are necessary in order to receive the crucial information for how to design this study and put together the results.

The system for feedback of quality errors to the assembly teams (n = 67 teams x 3 shifts) was implemented in the plant some months before the start of this research project, which may have led to underestimation of quality errors from the teams initially because of unfamiliarity with the system. Furthermore, the team leaders who are responsible for publishing the quality errors in the system admitted that they did not always have enough time for the task, which means that the amount of quality errors reported is probably too low. After contact with each team leader the official figures in the system were revised (increased) in a couple of cases, e.g. for the roof rails.

It must be remembered that there are many reasons why an assembly may fail. In this study all supplier-dependent errors are excluded, but cognitive ergonomics and psychosocial factors - such as perception of work instructions, experienced stress, forgetfulness, negligence and misunderstanding - also contribute to quality errors. This fact might explain why also assemblies with low physical load level have quality errors, although much fewer than the assemblies with high and medium physical work load. However, this study is aimed at measuring quality faults related to physical work load and therefore does not measure psychological and psychosocial factors specifically - despite the fact that these factors are involved in all assemblies to some degree.

It has been noted that many errors found and reported in the Product Verification System still remain in production. A plausible explanation for this is maybe that the design engineers have a very tough budget to keep and that unforeseen and non-quantifiable costs cannot be considered. Another reason might be that design engineers often do not recognize the consequences of a poorly designed product and work station due to lack of ergonomics competence and time (Broberg, 1997).

5. Conclusions

The conclusion is that there is definitely a strong relation between poor ergonomic assembly solutions and quality errors of the product found in production. This means that the assemblies in this study of high (n =19/18) and medium (n =17/16) load levels selected from the PV system before start of production (launch), were identified as risks already before the launch. Nevertheless they were accepted deviations from the requirement specifications for assembly ergonomics in new car projects despite being agreed requirements with the design engineers. However, in production the physical load level and risk for work related disorders are reduced to a certain extent through work rotation and various work devices and lifting aids. But there is still a huge impact on the product quality causing large numbers of quality errors that need to be taken care of before the cars leave the plant.

6. Further research

This paper aims at presenting the background, the methods used and some preliminary results. The next step in this study is to calculate the costs for corrective measures and repairs, scrap material and exchange of parts. The aim is to define a quality cost associated to each ergonomic issue and the overall purpose is to develop a tool that supports decision making in the design of new assembly concepts. The tool will have functionality to assess ergonomic conditions in terms of quality and productivity, interpreted in monetary terms.

Acknowledgements

This paper is partly a result of the research project 4D Ergonomics which is carried out within Virtual Ergonomics Centre (www.vec.se) and is financially supported by VINNOVA (the Swedish Agency for Innovation Systems) within the MERA (Manufacturing Engineering Research Area) program under the grant no. 2005-01998 and by the participating organizations (Alviva, Dassault Systèmes, Etteplan, SAAB Automobile, Siemens / UGS and Volvo Car Corporation). This support is gratefully acknowledged.

References

Axelsson, J., (2000). *Quality and Ergonomics – Towards successful integration*. PhD dissertation No. 616, Division of Quality and Human-Systems Engineering, Linköping: University of Linköping, Sweden, ISBN 91-7219-652-1, pp. 225-244.

Bäckstrand, G., Möller, S., Högberg, D., De Vin, L.J., Sundin, A., Case, K. (2005). A Roadmap towards Cost Calculation Methods Connected to Ergonomics Analysis and Simulation. *Proceedings of the 37th annual Nordic Ergonomic Society Conference*, Oslo, Norway, October 10-12, pp 312, ISBN 82-995747-1-4.

Broberg, O. (1997). Integrating ergonomics into the product development process. *International Journal of Industrial Ergonomics* 19: 317-327.

Chaffin, D. (2001). Digital Human Modeling for Vehicle and Workplace Design. *Society of Automotive Engineers, Inc*., Warrendale, USA.

Eklund, J., (1999). Ergonomics and quality management – humans in interaction with technology, work environment and organization. *International Journal of Occupational Safety and Ergonomics*, 1999, Vol.5, No2, 143-160.

Falck, A., (2002). Virtual ergonomics in car manufacture. *Proceedings of the 34th annual Nordic Ergonomic Society Conference*, Tammerfors, Finland.

Gröjer, J.E., Liukkonen, P., (1990). *Bok för Arbetsmiljön*. Arbetarskyddsnämnden, Stockholm, Sweden, 1990.

Hendrick, H., (1996). Good Ergonomics is Good Economics. *In Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting.* Human Factors and Ergonomics Society, Santa Monica, California, USA:

Lämkull, D., (2006). *Computer Manikins in Evaluation of Manual Assembly Tasks*. Department of Production and Production Development. Production Systems, Chalmers University of Technology, Göteborg, Sweden, 2006. ISSN 1652-9243, Report No. 14. Licentiate thesis.

Maudgalya, T., Genaidy, A., Shell, R. (2008). Productivity-Quality-Costs-Safety: A Sustained Approach to Competitive Advantage – A Systematic Review of the National Safety Council´s Case Studies in Safety and Productivity. *Human Factors and Ergonomics in Manufacturing*, Vol. 18 (2) 152-179.

OSHA, the European Agency for Safety and Health (2008): Fact sheet 76: National economics and occupational safety and health. 10.01.2008. Fact sheet 77: *The business benefits of good occupational safety and health*. 10.01.2008. URL: http://osha.europa.eu/topics/business/performance (Access date: June 2008).

Oxenburgh, M., Marlow, P., Oxenburgh, A. (2004). Increasing Productivity and Profit through Health and Safety: The Financial Returns from a Safe Working Environment. CTC Press: URL: http://www.crcpress.com. (Access date: June 2008). *Taylor & Francis*, ISBN 0415243319.

Oxenburg, M., Marlow, P. (2005). The Productivity Assessment Tool: Computer-based cost benefit analysis model for the economic assessment of occupational health and safety interventions in the workplace. *Journal of Safety research – ECON proceedings,* 36, pp. 209-214.

Stephens, A., Godin, C. (2006). The Truck that Jack Built: Digital Human Models and their Role in the Design of Work Cells and Product Design. *Society of Automotive Engineers*. Technical paper 2006-01-2314.