BENEFITS OF COLLABORATIVE ROBOTS IN ASSEMBLY –AN EVALUATION SCHEME

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Abstract: Programming, safety measures and handling of inflexibility still hinder robot implementation for many applications. However, advancements in several fields such as programming, human–machine-interfaces and safety system technology are about to change this. These advancements could make it possible for operators to collaborate with robots that assist operators at close range, without compromising safety, often referred to as cobot installations. The aim of the project was to produce a picture of how potential economic advantages can be evaluated from installations of cobot cells, to be compared with manual assembly and standard robot installations.

Keywords: Robots, cobots, assembly, man-machine integration

1. INTRODUCTION

Even though industrial robots steadily have improved their capacity and cost efficiency for many years, implementing them in actual production still requires substantial resources for programming, safety measures and handling of inflexibility. Robots also still have problems handling complex and soft components (Krüger, *et al.* 2009). These problems hinder robot implementation for many applications. However, advancements in several fields such as programming, robot sensor and control technology, force sensing, environment recognition, human–machine-interfaces and safety system technology are about to change this. These advancements could e.g. make it possible for operators to guide or collaborate with robots that assist operators at close range, without compromising safety, often referred to as cobot installations. Bley, *et al.* (2004) have shown that this mode of robot operation promise several potential benefits as it takes full advantage of robot as well as human strengths, while at the same time avoiding automation drawbacks. The technological developments and this mode of operation could make robot installations competitive for many more applications than today. Krüger, *et al.* (2009) e.g. refers to a study by Stanley Automation where they estimate that the use of intelligent automation devices (IADs) in assembly tasks can reduce injury costs, management costs and labor costs with 58%, leading to a payback time of less than 1 month. If cobot installations turn out to be as cost efficient as the Stanley Automation study indicates, this will make this type of robot installations very competitive and the range of operations that can be automated will increase significantly. Implementing this type of robot could hence add substantial value for producing companies and more detailed information on possible economical benefit could be useful.

However, even though there are clear potential benefits, a Scopus cobot and IAD search reveals that few sources outside Stanley Automation have focused on producing actual figures showing the practical economic benefit for cobot installations, in comparison with manual or standard robot assembly. This study therefore analyses what benefits that can be obtained by taking advantage of these new robot collaboration possibilities in practice and how these benefits can be measured and economically evaluated. The general aim of the project was to produce a scheme of how potential economic advantages from installations of cobot cells can be evaluated and compared to manual and standard robot installations. The general purpose was to contribute to the body of data that project leaders for future cobot installations will need in order to produce useful evaluations of the installations.

2. METHOD

A Scopus literature survey was conducted to identify possible benefits from cobot, robot and manual assembly stations that are important to evaluate. The study was also done to identify important factors to consider regarding the very procedure of evaluating different types of assembly cells. Three companies contributed with three, currently manual, assembly operations that have different types of problems that potentially could be cost efficiently solved using cobots. An analysis of the three assembly operations were conducted to get a more detailed and practical input regarding what a relevant evaluation scheme should cover. The data found in the literature on potential and actual benefit from assembly cell installations was used to develop the economic evaluation scheme for the study of the three future installations of cobots. The companies where the cobots are to be installed have extensive experience of manual production as well as installations and use of traditional, fenced in, robots cells. When executing the scheme it is assumed that the data these companies have from earlier introductions of manual assembly cells as well as robot cells, can be compared with observed data from the coming installations of the cobot cells, where one of the three cases will be a simulated installation, using a case study approach. The case study approach was chosen since it is an empirical inquiry that investigates a contemporary phenomenon within its real-life context (Yin, 1994) and therefore suits the objective of an evaluation study.

3. STUDY IN SCOPUS AND OF CHOSEN ASSEMBLY OPERATIONS

3.1. Parameters to evaluate

There is a substantial body of research concerned with the issue of how to make efficient investments in advanced machinery such as robots. Handbooks are developed that list many parameters that should be considered when evaluating robot cells, e.g. labour cost, product quality and material waste (see e.g. Nof (1999) p. 677). Cil (2004) emphasizes that robot benefits should be considered on several levels such as strategic, operational and economic, where he mentions the CDSS system as a method that requires fewer, but still several resource demanding steps. Parameters found in handbooks and in other sources are more general parameters for all types of installations of advanced machinery that should be part of an evaluation scheme. However, several parameters interesting for the evaluation of specifically human-robot collaborations were also found in the literature:

- Jarasse, *et al.* (2014) discusses the importance of *role assignment* between robot and human and concludes that more work has to be done to secure that an efficient role assignment method is used.
- Weistoffer, *et al.* (2013) studies *acceptability* of these types of installations and found that it was robot appearance dependent. Anthropomorphic robots were not necessary better accepted, perhaps due to of uncanny valley effects. They found though that industrial robots should have humanlike movements.
- *Set-up time.* Kus, *et al.* (2008) have analyzed the requirements of small and medium enterprises (SME). They found that one of the most important disadvantages of using robots compared to manual assembly was that reprogramming requires expert knowledge. Programming improvement has, however, led to robots that can be programmed by taking the arm of the robot and showing the robot what it should do. This can reduce the time it takes to integrate robots into factory operation from typically 18 months, to 1 hour (Brooks, 2013).
- Krüger, et al. (2009) have analyzed potential benefits from *tact time reductions* using a net present value calculation. They found that a hybrid collaborative robot solution had an NPV that was 25% higher than a standard robot cell and substantially higher NPV than a manual solution.

3.2. Evaluation considerations

To make the evaluation of specific parameters as relevant as possible, the context has to be considered:

- Hedelind and Jackson (2011) studies *benefit from a lean perspective* and have in this context defined lean automation using (Dulchlnos and Massaro, 2005, p. 26) "Lean automation is a technique which applies the right amount of automation to a given task. It stresses robust, reliable components and minimizes overly complicated solutions". Hedelind and Jackson (2011) found that *lack of information* from what caused production standstills hampered possibilities. "Swedish companies were very focused on the technology used and had a lot of opinions and discussions around the choice of technologies to use. At the Japanese companies, the production management had little interest in the technical solutions." They found that it is not necessarily a conflict between lean and automation, but that providers want closer contacts with applications to ensure maximum benefit from robots in a lean environment.

- Karsak (2008) studied choosing robots through the use of an integrated fuzzy logic technique. Although it is usually assumed that the specified performance parameters are mutually independent, in general, *performance parameters provided by robot vendors are not achievable simultaneously*. For instance, Offodile and Ugwu (1991) reported that for a Unimation PUMA 560 robot manufacturer-specified repeatability deteriorated as the speed increased beyond 50% of the status speed and the weight increased beyond 0.91 kg. "Further, it is very difficult, if not impossible, to determine the functional relationship between these parameters. Hence, making this assumption introduces a risk of selecting a robot that might fail to provide the required performance."
- The level of automation can be described as a continuum, ranging between totally manual and totally automatic (Frohm, 2008). It is important to find both *the level and type of automation that best suits the needs and requirements of the environment in which the automated equipment should be used*. Säfsten et al. (2007) e.g. address the concept of *rightomation*. An evaluation scheme should hence produce results than can be viewed in the light of environment requirements.
- Also, one of the main reasons that an automation project ends in failure is unrealistic or undefined objectives (Frohm, 2008). *A well formulated specification of requirements is therefore of great importance* (Friedler and Granlund, 2012). An evaluation scheme should hence produce results than can be viewed in the light of the specification quality.
- Yu and Gil (2012) introduce an intuitive manipulation device (IMD) which significantly improves performance (speed) and computational load when lifting large panels. The *force control method* for assembly of large panel is a valuable tool to improve the convenience of users as well as protecting the fragile panel against an unexpected environment. This kind of approach however, requires a heavy calculation load for control system and increasing expensive sensors. Their study indicates a more than 70% improvement in performance using their method.

At a resently held industrial conference on cobots (in Boston, USA), the robot cells on display were installed with small robots and lightweight components. The reason for using small robots was that these installations are possible today. However, during break discussions it became clear that handling of heavy components and using large robots is also a field of research in the US (Schlenoff, 2014). The break discussions made it clear that the safety issues are handled in the same way in the US as in Europe. The US seems to adapt the ISO standard for safety in the same way as is done in Europe. The suggested cobot evaluation scheme should be useful for any type of cobot installation. However, solutions for handling of heavy equipment is assumed to be of particular interest and the case 1-3 below is chosen with this assumption in mind.

3.3. Specific assembly operation case 1 – Placement of aero panels under a vehicle

In the first case a robot would be used in order to place aero panels under a vehicle. The aero panels limit the emissions of CO_2 when the vehicle is used. This is a standard component in about six different variants per vehicle. Furthermore, the panels differ between vehicles due to i.e. size. The panels are stable from a geometric point of view. The panels are large but light-weighted (about 4 kg) since they are made in a polymer. The assembly work is today performed in a non-ergonomic way with placement with an under-up-work (see fig. 1). If a robot in collaboration with an operator could do this placement the process will be very flexible and the ergonomic situation for the operator could be improved. The robot can place the panel with the aim of managing the weight and the operator can use a handhold tool for assemble the clips. There is a need for assemble many clips with high precision.

The robot could also work as a kitting support to the operator by selecting the right panel at the right moment. This is noticed as a possibility to reduce the need for production area for storing different variants of panels. The amount of variants is predicted to increase in the future. A vision system keeps track of the assembly stage so that the correct part for the current model/version of the product is handled over at the correct time. This decreases the mental stress of the operator and ensures that correct parts are assembled.

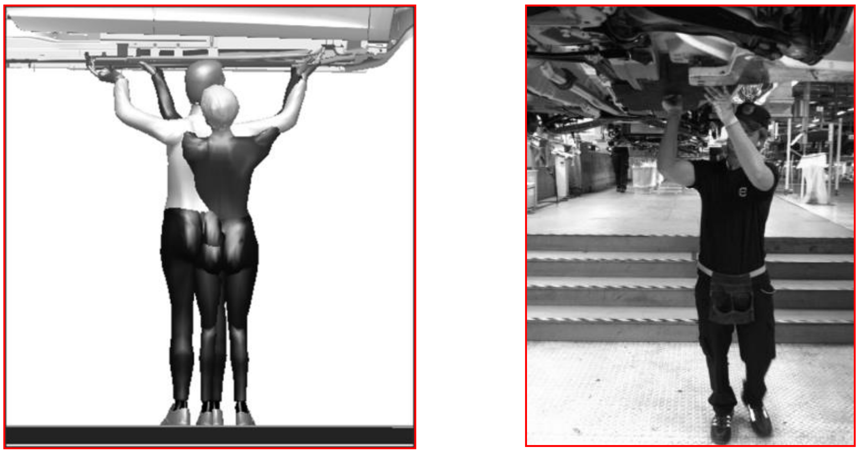

Fig. 1. Non-ergonomic placement of aero panels, requiring a specific length for operators.

3.4. Specific assembly operation case 2 – Heavy and repetitive lifting

In the second case a robot would be used as a lifting device picking and executing a desired trajectory, with the aim to assemble a heavier component and position the object in the right position in relation to guiding pins. The pins will provide a friction that is used in the assembly and that the robot must manage. Today is the operation done manually and the object is assembled in an angel of approximately 45 degrees to give the operator a more ergonomic situation. However, this operation is still not satisfying from an ergonomic point of view.

The idea of the case is that an operator guides the robot to a subassembly and then to the final position with the object and the operator receives support from the robot in order to push the component over the pins with friction. This means that the robot first acts as a handling device, serving the operator with the correct object. In the second step the robot is a lifting aid, the operator does not have to lift anything solely placing the object in the correct position. The operator then proceeds with following operations, as for example tightening screws or other parts (see fig. 2 for assembly sequence). The selected object exists in 3-5 variants but demands high precision and the possibility to push with some force to overcome friction.

Another task within this area is for example assembly of wheels to trucks. The wheel is heavy and must be turned into the right position for the screws to fit correctly in the holes.

Fig. 2. Assembly sequence: Lift flywheel cover, put cover in an automated silicon applying machine and aid the assembly operator when assembling cover on engine block by carrying the heavy load.

3.5. Specific assembly operation case 3 – Interior assembly in truck cab

The two previous cases are, to some extent, combined in case 3. Many components that are assembled in a truck cab are large and rather heavy. Examples are dashboard, ceiling lining, beds and various storage drawers. These are currently assembled with the operator inside the cab and another operator working outside the cab picking up the parts with the lifting device and supporting it to the operator inside the cab. If a robot could perform the lifting of the cockpit from the conveyor belt, to the sealing station and then into the cab, the task could be performed as a one person task instead of a two person task. The selected part is the cockpit and it has an application of a sealant prior to the assembly. The robot application of the sealant also has the potential result in better sealant application quality. The add-on difficulty in this case, compared to the first two cases is that the cab is placed manually, i.e. the position on the belt is not well defined, on a continuous moving belt conveyor.

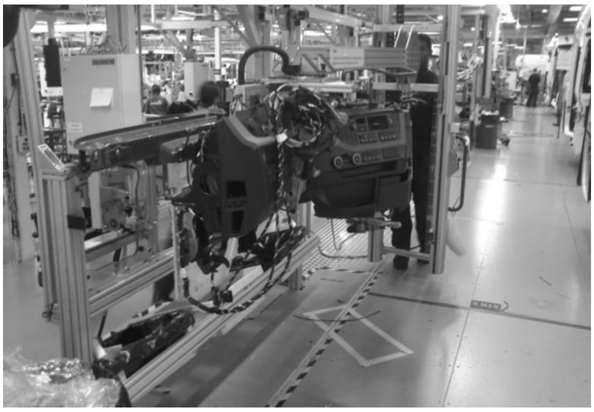

Fig. 3. The cockpit to be automatically lifted from conveyor belt, to sealing station and then inserted into the cab.

3.6. Case study considerations

As a research method, case studies often consist of several methods for gathering information (Yin, 1994). During the envisioned case studies above, data is to be collected using three data collection methods: interviews, documentation and observations. The three different methods, which are further described below, can make it possible to triangulate information.

Interviews should be conducted with the production manager, the production engineering managers and production engineers. An interview guide should be used to ensure the same topics and questions throughout the interviews. The interviews should cover topics such as: current manual work routines, consequences of robot collaboration and current methods to decide value and measure cost for manual and standard robots assembly. The gathered documents should consist of data, calculations, etc. The observations, which partly should be of participating character, should consist of closely monitoring existing manual assembly cells.

From the collected data, production values (capacity, goods quality, useful information, etc) and costs required to secure the production value (labor, machinery, safety, etc) should be identified. That is, values and costs for the three different assembly cells, manual, robot and cobot should be identified for possible comparison. During this stage the data should be analyzed for discrepancies and contradictions but also evaluated with the aim to highlight strengths, weaknesses and potential problems. During a workshop the resulting value expression should be presented to the company to both validate the results and also further develop them together with the case companies.

4. ANALYSIS

4.1. Parameter check list.

An analysis of the literature and the chosen assembly operations indicate that the factors most relevant to consider when evaluating cobot installations are:

- *Set-up time.* The improvements in programming techniques are specifically useful for cobot installations but could help reduce set-up time for stand-alone robot cells as well. A cobot installation requires reduced programming compared to today's robot cells. This is due to the fact that the precise programming is limited to the picking area whereas the assembly is limited to a position where the operator starts the guiding (assembly) operation.
- *Reduction of manual labor hours*. What will a comparison between manual, robot and cobot cells reveal? When choosing the cockpit assembly as one case in the project, several other cases were discussed. There were several cases were a cobot installation, most likely, could have reduced the manning from two to one person.
- *Ergonomics*. How much more ergonomic can a cobot installation handle an aero panel placement under a vehicle, compared to current manual assembly? The case with the aero panels shows that ergonomics can be a key factor for justifying an investment.
- *Handling of soft/complex components*. Is it possible that a cobot solution can handle an installation of a truck dashboard, which is an operation that currently cannot be cost efficiently automated?

- *Distortion compensation*. One case includes assembly of components that needs individual adjustments in order to make assembly possible. How much more cost efficient can this assembly be carried out with a cobot installation? This is an issue where cobots are expected to be very efficient. There is no need for exact positioning nor for complicated grippers since the operator takes care of the final positioning.
- *Production layout*. Can the use of a cobot make it possible to have a more cost efficient layout of component supply to the assembly station? One example is that the materials façade can be different when the operator does not have to reach the picking. Parts may be placed at higher or lower potions compared to when humans are picking.
- *Safety*. Developments in safety system technology indicate that it should be safe for operators to work at close range and collaborate with robots, using an enabling device to control the robot. It is, today, almost impossible to state whether the safety will be a significantly higher cost or if it will be lower. One issue is also what to compare with. If cobot technology makes formerly impossible cases possible – what is the alternative in a safety aspect?
- *Useful information.* The ability of an assembly cell to make use of relevant information from company business systems, production systems and other sources, as well as the ability to provide useful information to production and business systems, are ever more important factors for production competitiveness. This information handling can often be automated along with physical assembly automation, rendering automation interesting for this reason alone. A cobot cell could complicate the information handling as the robot as well as the operator have to handle assembly information, making this factor interesting for evaluation.

Several more factors, collected from handbooks and other sources need to be analyzed for comparison of different cells and they are collected in table 1, which is divided into two sections, costs and value. “Costs” are costs necessary to secure production ability. “Value” is the economical value of parameters describing the production ability. It is assumed that costs and value can be expressed as “cost/unit” and “value/unit”. That is, it is assumed that an increased cost for e.g. equipment maintenance will correspond to an increased value from increased equipment availability. Several value parameters are correlated to each other. E.g. the value of ability to automatically handle complex components is derived from the savings that can be made on reduction of manual labor. The value of the ability for automated distortion compensation is also derived from the value of savings that can be made on reduction of manual labor, but it can also be derived from the value of increased (or reduced) goods quality resulting from misaligned assembly of components. The value of being able to implement lean production is derived from the combined factors that make this mode of production valuable.

Table 1. Parameters to be evaluated.

Parameters	**Manual assembly**	**Standalone robot cell**	**Cobot cell**
Production costs			
Commissioning			
Investment			
Installation			
Set-up and Programming			
Manual labor			
Maintenance			
Cell/equipment upgrading			
Safety			
Component supply			
Production layout			
Component design			
Production value			
Cycle time			
Tact time			
Availability/Up-time			
Handling soft/complex components			
Precision/goods quality			
Distortion compensation			
Information quality			
Ergonomics/Injuries			
Lean production/Flexibility			

Other strategic considerations			
Other (toilets, parking, etc)			

4..2 Evaluation consideration check list

The relevance of results in table 1 regarding the possibility to compare different types of assembly methods will be determined by a number of factors. In order to reduce the risk of facing the "comparing apples and pears" fallacy, when different cells are compared, the literature study indicates that it has to be asked:

- Have the cells to be compared been given comparable and relevant specifications?
- Are the automation levels for the cells to be compared properly chosen, with comparable methods?
- Has machinery been chosen with comparable and relevant methods?
- Is the information supply to the cells of comparable quality?
- Is the component supply to the cells comparable?
- Do the assembly cells have comparable and relevant control systems?
- Do they have comparable dimensioning?
- Are the cells maintained and upgraded in comparable ways?
- For the cobot cell, has the role assignment been handled in a competitive manner?
- Other factors that could render comparisons moot?

If any answer above is "no", can results in table 1 be adjusted to compensate and make comparisons possible?

This evaluation consideration checklist will not guarantee that the fallacy can be avoided, but it will highlight potential problems and reduce the risk.

By applying the evaluation scheme the cost efficiency of alternative assembly cell solutions in general can be decided. By emphasizing the parameters identified as especially important for cobots, case study evaluations of cobot installations hence have the potential to decide feasibility as well as competitiveness, compared to alternative cells.

5. CONCLUSIONS AND FUTURE RESEARCH

Future cobot research will focus mainly on technical issues, together with safety issues, since these are the main obstacles for cobot installations. The authors of this work point out that the economical issues should be studied in paralell. The integration of economic value issues might make it possible to, at an early stage, choose cobot installations that are both technically and economically justifiable. An evaluation scheme for comparisons of alternative assembly cell solutions, cobot solutions included, was hence developed. This scheme can be used for case studies where general feasibility, as well as economic competitiveness for cobot cells, can be evaluated. Actual cobot case studies need to be carried out in order to verify the usefulness of the evaluation scheme.

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REFERENCES

Bley, H., G. Reinhart, G. Seliger, M. Bernardi, T. Korne (2004) Appropriate Human Involvement in Assembly and Dissassembly, *CIRP Annals – Manufacturing Technology*, **Vol. 53, No 2**, pp.487-509.

Brooks, R., 2013, Robots at Work: Toward a Smarter Factory, *The Futurist*, May-June, pp. 24-27.

Cil, I. (2004). Internet-based CDSS for modern manufacturing processes selection and justification. Robotics and Computer-Integrated Manufacturing **Vol. 20, No. 3**, pp. 177-190.

Dulchlnos, J. and P. Massaro (2005). The time is right for labs to embrace the principles of industrial automation, *Drug World Discovery*, Winter, pp. 25-8 (2005-2006).

Frohm, J. (2008). *Levels of Automation in Production Systems*, Doctoral thesis, Department of Product and Production Development, Chalmers University of Technology, Göteborg, Sweden

Friedler, N. and A. Granlund, (2012). Defining the automation equipment acquisition process – from a system supplier's perspective, *The 22nd International Conference on Flexible Automation and Intelligent Manufacturing*, 10-13 June 2012, Helsinki, Finland

Hedelind, M. and M. Jackson (2011). How to improve the use of industrial robots in lean manufacturing systems. *Journal of Manufacturing Technology Management*, **Vol. 22, No 7**, pp. 891-905.

Jarrassé, N., V. Sanguineti, et al. (2014). Slaves no longer: Review on role assignment for human-robot joint motor action. *Adaptive Behavior*, **Vol. 22, No 1**, pp 70-82.

Karsak, E. E. (2008). Robot selection using an integrated approach based on quality function deployment and fuzzy regression. *International Journal of Production Research*, **Vol. 46, No. 3**, pp. 723-738.

Krüger, et al. (2009). Cooperation of human and machines in assembly lines. CIRP Annals - Manufacturing Technology **Vol. 58, No. 2**, pp. 628-646.

Kus E, R. Grüninger and R. Hüppi (2008). Technological scenario for the robot market diffusion. Contribution to Task 5, WP5 of the ARFLEX project, September.

Nof, S.Y. (1999). *Handbook of Industrial Robotics, Vol 1*, John Wiley & Sons Inc., New York

Offodile, F. and K. Ugwu (1991). Evaluating the effect of Speed and Payload on Robot Repeatability. *Robot Comput.-Integr. Manuf.*, *Vol. 8 No*. 1, pp. 27-28

Schlenoff, C., (2014). Cognition and Collaboration Group Leader, National Institute of Standards and Technology. Discussions at the Collaborative Robots Workshop, organized by RIA (Robotics Industries Association), Boston, MA, USA, April 16th

Säfsten, K., M. Winroth, and J. Stahre, (2007). The content and process of automation strategies, *International Journal of Production Economics*, **Vol. 110, No. 1-2**, pp. 25-38

Weisstroffer, W. (2013). A methodology to assess the acceptability of human-robot collaboration using virtual reality. *Proceedings of the ACM Symposium on Virtual Reality Software and Technology*, pp. 39-48.

Yin, R. K. (1994). *Case Study Research Design and Methods*, SAGE Publications Inc., London.

Yu, S., M. Gil, (2012). Manipulator handling device for assembly of large-size panels, *Assembly Automation*, **Vol. 32, No. 4**, pp. 361 - 372