Life Cycle Evaluation of Factories: The Case of a Car Body Welding Line with Pneumatic Actuators

Tim Heinemann, Alexander Kaluza, Sebastian Thiede, Daniel Ditterich, Johannes Linzbach, Christoph Herrmann

To cite this version:

Tim Heinemann, Alexander Kaluza, Sebastian Thiede, Daniel Ditterich, Johannes Linzbach, et al.. Life Cycle Evaluation of Factories: The Case of a Car Body Welding Line with Pneumatic Actuators. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2014, Ajaccio, France. pp.546-554, 10.1007/978-3-662-44733-8_68 . hal-01387319

HAL Id: hal-01387319
https://inria.hal.science/hal-01387319

Submitted on 25 Oct 2016

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution 4.0 International License

Life Cycle Evaluation of Factories: The Case of a Car Body Welding Line with Pneumatic Actuators

Tim Heinemann[1], Alexander Kaluza[1], Sebastian Thiede[1], Daniel Ditterich[2], Johannes Linzbach[2], Christoph Herrmann[1]

[1]Technische Universität Braunschweig, Institute for Machine Tools and Production Technology, Chair of Sustainable Manufacturing- and Life-Cycle-Engineering, Braunschweig, Germany
[2]Festo AG & Co. KG, Esslingen, Germany

t.heinemann@tu-braunschweig.de

Abstract. During the planning phase of the build up or overhaul of factories a large share of the life cycle spanning impact of such production facilities is determined. Furthermore it is very hard to evaluate the impact of possible measures for improvement, resulting Total Cost of Ownership (TCO) and environmental impacts of factory systems. Against this background this paper presents an integrated life cycle analysis approach for a streamlined economical and environmental life cycle assessment of factory systems. The approach gets applied while using two interacting tools for a) energy efficiency evaluation of pneumatic systems and b) life cycle evaluation of factory systems.

Keywords: life cycle evaluation, total cost of ownership, streamlined LCA, factory evaluation, sustainable manufacturing.

1 Introduction

When planning projects for new or overhauled factories are started, there is a high degree of freedom about the configuration of the machines, the technical building services (TBS) and the building shell. Also most of the later costs as well as environmental impacts (esp. for the use and disposal phase of the factory) get determined at this stage. However, most of the information for a severe quantification of the financial and environmental impacts of planning alternatives are not available so that wrong decisions can be taken easily. Especially when it comes to add-on measures to reduce the environmental impact, often the budget restrictions impede the implementation as the TCO and financial benefits as well as the environmental improvements cannot be estimated sufficiently. This problem will be solved by applying a Life Cycle Evaluation (LCE) Approach, which becomes manifest in the LCE Tool [1]. This tool gets applied in combination with a specific tool for the evaluation of pneumatic and electrical actuator systems to calculate the economical and environmental impact of alternative system designs and improvement measures.

2 Theoretical background

Holistic system comprehension and factory elements

In contrast to many approaches, which divide the factory planning process into sequences and induce a sequential planning of factory elements (e.g. [2]), this paper introduces a holistic system comprehension of factories, in which all factory elements are of equal importance. This is because in industrial environments all factory elements influence each other regarding the overall resource consumption. The introduced evaluation approach focuses on the factory system and its subsystems [3] [4]:

- production equipment: processes/machines/value adding process chains
- technical building services: responsible for providing production conditions and energy as well as media (e.g. compressed air)
- building shell: physical boundary of the factory system and to the outside

However, their individual design and control involves diverse disciplines which impedes a synergetic planning of the factory system. Thus, methods to overcome those interdisciplinary challenges are a proper way towards more sustainable solutions.

Life cycle evaluation

Life cycle evaluation (LCE) in the context of this paper addresses the evaluation of financial (Total Cost of Ownership, TCO) and environmental impacts (CO_2eq.) which result from physical flows during all life cycle phases of the factory system.

TCO is a selected perspective on life cycle costing (LCC), which considers all economically relevant monetary flows over the life cycle of products. Therewith, LCC allows analysing trade-offs between life cycle phases and supports to derive solutions from a comprehensive perspective [5]. Diverse frameworks for LCC in form of standards, norms or guidelines have been developed (e.g. VDMA 34160, VDI 2884, DIN EN 60300). TCO focuses solely on the operator/user perspective of the considered object and all the costs that occur during the course of ownership. To ease application, software based tools which also differ in terms of scope, field of application and general functionalities have been developed (e.g. [6]). However, those solutions tend to be quite specific for selected applications and less considering systems as a whole [1].

The calculation of environmental impacts can be done via Life Cycle Assessments (LCA). LCA focuses mainly on environmental impacts throughout a product's life cycle from raw material acquisition through production, use and end-of life treatment. It builds upon Life Cycle Inventories (LCI), which sum up the physical flows along the life cycle of a product [7]. From a product perspective the incorporated materials are usually well known and easy to assess in LCAs. However, the additional physical (energy/media) flows which occur during the manufacturing phase especially within a factory system are often hard to assess and demand for supporting tools (see also [1]).

3 Factory life cycle evaluation approach

Architecture of the approach and tool

All calculations and evaluations within the LCE approach are based on life cycle inventories (cumulated physical input and output flows) of the focused system, which can be a system element like an assembly line (see Fig. 1).

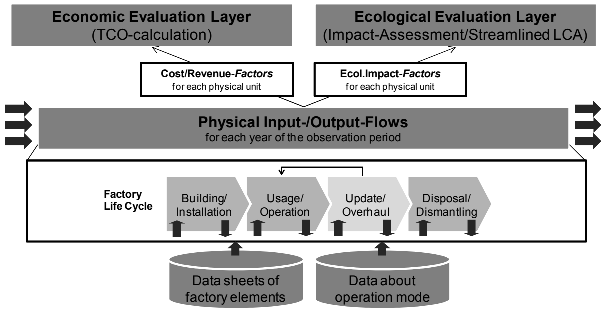

Fig. 1. Architecture of the life cycle evaluation approach

These flows are based on resource consumption profiles which are taken from data sheets and (simulated) forecasts of the factory's operation modes. During the use phase of the factory also the utilization, shift models, downtimes, etc. are used to calculate the overall physical flows. Every factory element gets described as a set of parameters with physical units. All evaluation is done by transforming the physical flow data into financial or environmental impacts by multiplying it with cost factors as well as environmental impact factors (e.g. CO_2eq.). This calculation gets supported through an Excel based tool, which supports the main parameterization of the individual factory system model through default templates of factory elements. Therefore the modelling and evaluation of alternative strategic factory settings gets facilitated for quick assessments in an early stage of the planning process. Fig. 2 shows an overview over the elements of the LCE Tool. Through these elements (user interface, reporting sheets, etc.) the usability gets enhanced. (For a deeper inside in the LCE tool and its data bases e.g. for environmental impacts of the building shell please see [1].)

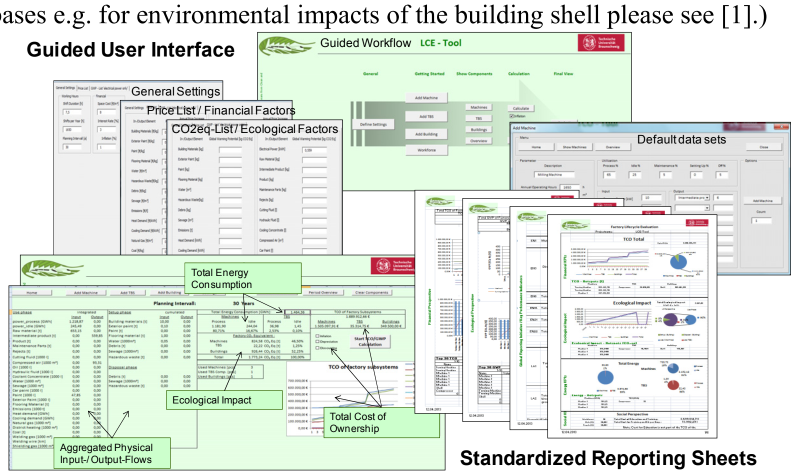

Fig. 2: Overview over the elements of the Life Cycle Evaluation Tool

Tool interaction for enhanced evaluation options

As the LCE approach demands reliable input data (e.g. technical behaviour of machines), it has to incorporate data from other tools. Especially in planning stages, when real consumption profiles of factory elements are not accessible, tools which simulate element or system behaviour become relevant. Furthermore the LCE Tool only considers factory elements down to the level of detail of machines, TBS or building shells. It cannot consider the behaviour of components (at acceptable effort). E.g. the behaviour of pneumatic components and resulting loads for compressors illustrate the resulting interplay of detailed machine component behaviour and the resource consumption of factory elements. Fig 3 visualizes an exemplary interplay of tools as it will be applied in the case study, which will be described afterwards.

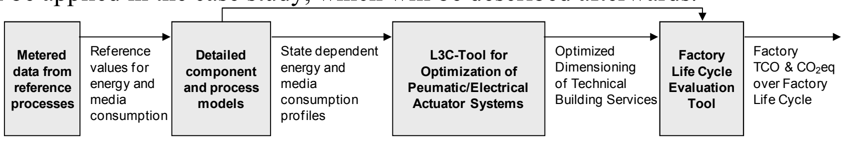

Fig. 3. Tool interplay and information flow

Supporting tool for the evaluation and optimization of pneumatic actuation systems

The LCE Tool benefits from an application of tools like the Life Cycle Cost Calculator (L3C-Tool**,** Festo AG & Co. KG**)**, which can model actuation systems at a very high level of detail regarding single (pneumatic as well as electrical) actuation operations, resulting compressed air and electricity consumption (see Fig. 3). The L3C-Tool enables the right dimensioning of air compressors and the evaluation of improvement measures to the system of actuators, valves and tubes (see Fig. 4) [8].

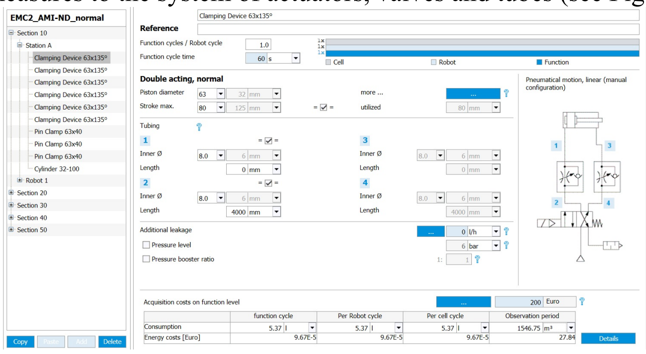

Fig. 4. Dimensioning of pneumatic system and calculation of compressed air demand in L3C-Tool (screenshot) [8]

A major advantage of the L3C-Tool is its ability to conduct transparent and comprehensible energy consumption calculations. This allows a direct cost comparison of different factory design options. Hence, this tool addresses the following main functionalities:

- Modelling of systems on component level and aggregation to machine level
- Calculation of energy costs and investment costs
- Performance of break-even analyses between different system configurations

The L3C tool also aims at identifying energy efficiency improvements, while quantifying energy saving potential, payback time for investments and maintenance costs. Thus, decision makers can carry out an energy diagnosis of configuration alternatives with little effort. Further information about the L3C-Tool can be found in [8] and [9].

4 Case study: Optimized planning of car body welding line through improved compressed air systems

Case description and evaluation scenarios

The LCE and the L3C analyze a car body welding line, focussing on pneumatic and electrical actuators synergistically. The case is fictional, but the used data represents a realistic behaviour of a possible manufacturing line. The impacts of sample measures are analyzed, which get translated into financial and environmental KPIs through the LCE Tool. The car body welding line consists of different actuators within the manufacturing application, a compressor station and a building shell (exemplarily: Fig. 5).

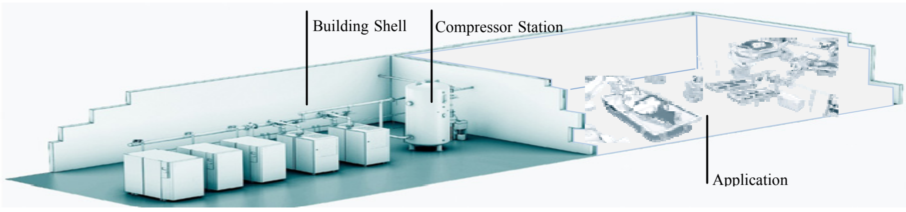

Fig. 5. Conceptual sketch of the analysed system, regarding the three factory elements (Festo AG & Co. KG)

As main improvement measure an optimization of the pneumatic components reduces the compressed air consumption of the system. Thus, the compressor can be resized compared to the standard setting with a conventional compressor. In order to highlight the broader evaluation potential of the LCE Tool further possible improvement measures will be evaluated exemplarily as well. Due to simplification reasons only the consumption of electricity has an influence on the environmental impact of the factory's use phase. Furthermore, the building shell only creates emissions during its setup and disposal phase. The evaluation time horizon is 30 years of use phase plus a setup and disposal of the factory. Tab. 1 introduces a selection of parameters, which describes the base scenario, and the parameter changes of improvement measures.

	Base scenario: Automotive car body welding line A car body welding line is used as reference. The model consists of a selection of the machines of the manufacturing line, the TBS (compressor station) and a sample building shell. The compressor capacity meets the demand of a car body factory as figured out with the L3C-tool. For the building shell a predefined reference factory has been used [1]. The following model parameters have been used besides others: ▪ General: Annual operating hours: 4800 h; European electricity mix, price increase 1%/a ▪ Manufacturing line: Process power: 69.1 kW; lifetime: 72000 h; maintenance interval/expenses: 4800h/~30k€; Investment: ~830 k€ ▪ Compressor: Process power: 171 kW; lifetime: 24000 h; maintenance interval/expenses: 4800h/~19 k€; investment: ~94 k€ ▪ Building shell: Aerated concrete walls, no windows; lifetime: 165000 h; maintenance interval/expenses: 4800h/~33 k€; investment: ~650 k€
Orga. measures	**Scenario 1: Alternative shift model** Application of an alternative shift model that might occur due to changing demands or the introduction of measures for improved working conditions. ▪ Applied parameter changes: 2 shifts (3200 working hours) instead of three shifts ▪ Sensitivity analysis: +/- 10% working hours
	Scenario 2: Alternative energy mix Substitution of the European Electricity mix with certified renewable electricity supplies.

	▪ Applied changes: Usage of the Swiss renewable energy mix (0.0098715 kg CO2eq/kWh instead of 0.559 kg CO2eq/kWh; price increase about 0.0015 €/kWh [10] [11] ▪ Sensitivity analysis: +/- 10% energy price
Technical measures	**Scenario 3: Improved pneumatic components and system design, based on the recommendations from the L3C-Tool** Improving the compressed air system is a lever for decreasing energy cost in production [12] [8]. Overall system design (up to 9%), leakage detection (up to 20%) or more efficient compressors (up to 15%) can reduce the energy consumption significantly [12] [13]. For Sc. 3 a smaller compressor is installed due to improved pneumatic components, a more advanced system design and leakage detection. The total investment is assumed to remain constant as the measure's implementation costs equalize the reduced compressor investment. The impact on the whole factory gets assessed. ▪ Applied changes: Air compressor: 33% less electrical power input (115 kW instead of 171 kW) ▪ Sensitivity analysis: +/- 10% electrical power input of air compressor
	Scenario 4: Energy efficient drives By increasing the energy efficiency of drives (e.g. according to the IEC 60034-30 standard) from class IE1 to IE3 efficiency increases of about 10% can be achieved [14]. ▪ Applied changes: Drives: 10 % less electrical power input (62.2 kW instead of 69.1 kW for the considered section of the body welding line); Machine investment costs: +10% ▪ Sensitivity analysis: +/- 10% electrical power input of production machines

Tab. 1. Scenario description

Results

The car body manufacturing scenario could be modeled successfully within the Festo L3C-tool and the LCE-tool. Even though the LCE tool allows a separate simulation of the factory, the cumulated input data out of the L3C-tool enhanced a flawless application. Four scenarios have been applied in order to test the flexibility of the LCE-tool and the sensitivity of its results. For that matter the TCO and the greenhouse gas emissions (kg CO_2eq) have been evaluated (see Fig. 6 and Fig. 7.). An additional sensitivity analysis for Sc. 3 has been carried out (see Fig. 8).

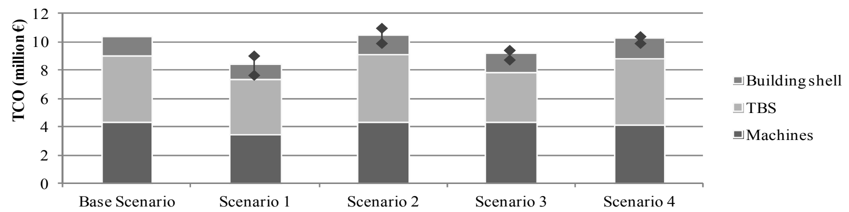

Fig. 6. Scenario evaluation results from LCE Tool, Total Cost of Ownership

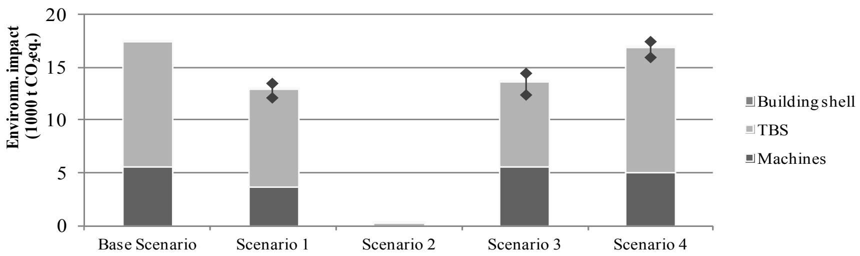

Fig. 7. Scenario evaluation results from LCE Tool, environmental impact (1000 t CO_2eq.)

The evaluated organizational measures include the change of the shift model (Sc1) and the use of a certified renewable energy mix (Sc2). Whereas the reduced working hours result in lower TCO (-19%) and greenhouse gas emissions (-26%), it has to be considered that the factory output would decrease simultaneously, not regarding additional efforts (e.g. ramp up and shutdown times). The change of the used electricity mix shows slightly higher TCO. The calculated carbon emissions decrease by 99%.

Variations in the installed compressor capacity (Sc3) and the use of more efficient electric drives (Sc4) have been discussed as technical measures. Based on the L3C-tool application and its optimization on component level, the use of a compressor with 33% less power demand becomes possible. This decreases the TCO by 11% and the carbon emissions by 22% (Sc3). Only marginal savings (2% TCO and 3% carbon emissions) could be achieved in Sc4. Based on these results, Sc. 3 has been selected to evaluate the influences of relevant input parameters on the TCO in more detail. A sensitivity analysis varies the compressor's electrical process power, changes energy prices as well as compressor lifetimes (Fig. 8). Increased compressor lifetimes are assumed due to the improved pneumatic system design.

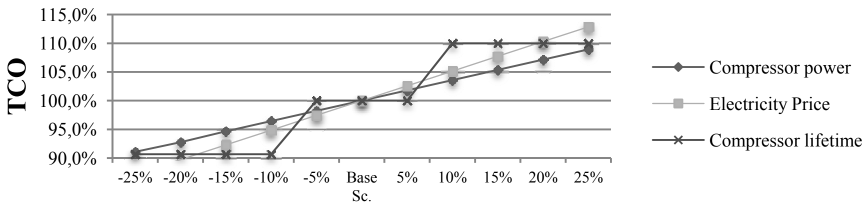

Fig. 8. Sensitivity analysis for TCO regarding variations of electricity price, compressor lifetime and compressor power

Varying process power and energy prices show linear sensitivity effects. A larger influence can be observed for energy prices due to their influence on the factory system. The compressor lifetime shows a staircase-shaped course. This effect is induced by investments that become necessary for replacing compressors after their use phase.

5 Summary

This paper presented an approach for a rapid life cycle evaluation regarding the economic (TCO) and environmental (CO_2eq.) impact of factory systems. This approach has been applied to a sample case of a car body welding line. In order also to assess the effect of changes in the configuration of its pneumatic actuation system, the specialized L3C-Tool was used and an optimized dimensioning of the air compressor set could be derived. The life cycle spanning effect of a variation of this factory system element has been evaluated as one improvement scenario via the LCE Tool. The effect of this measure has been compared to other technical as well as organizational improvement measures. By doing so the potential of an interaction of these tools was illustrated. As a result and according to the previously introduced holistic system comprehension of factories factory planning representatives should jointly assess the economical and environmental impacts of factory configuration options already at an early planning stage and under equal consideration of all factory elements.

6 Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 285363. The funded project's title is "Eco Manufactured Transportation Means from Clean and Competitive Factory" [EMC2-Factory]. For further information about the project please visit the website www.emc2-factory.eu.

References

1. Heinemann, T., Thiede, S., Müller, K., Berning, B., Linzbach, J., Herrmann, C. (2013): Life Cycle Evaluation of Factories: Approach, Tool and Case Study, in: Proceedings of the 11th Global Conference on Sustainable Manufacturing (GCSM2013), pp. 529-534
2. VDI-guideline: VDI 5200 factory planning – planning process/VDI-Richtlinie: VDI 5200 Blatt 1 Fabrikplanung – Planungsvorgehen
3. Herrmann, C., Kara, S., Thiede, S., Luger, T. (2010): Energy Efficiency in Manufacturing – Perspectives from Australia and Europe, in: Proceedings of the 17th CIRP International Conference on Life Cycle Engineering, pp. 23-28
4. Thiede, S. (2012): Energy Efficiency in Manufacturing Systems. Springer, Berlin, pp. 38-39
5. Herrmann, C. (2010): Ganzheitliches Life Cycle Management, Springer, Berlin, pp. 131-150
6. Thiede, S., Spiering, T., Kohlitz, S., Herrmann, C., Kara, S. (2012): Dynamic Total Cost of Ownership (TCO) Calculation of Injection Moulding Machines, in: Proceedings of the 19th CIRP Conference on Life Cycle Engineering, pp. 275-280
7. Life cycle assessment – requirements and guidelines DIN EN ISO 14044:2006, DIN October 2006
8. Tools zur Planungsunterstützung (2013), in: Green Carbody Project Consortium (2013) (eds.) Planung des effizienten Einsatzes von Druckluft im Karosseriebau, pp. 59-64. http://www.festo.com/net/SupportPortal/Files/327813/Greencar_Leitfaden_PDF_MD.pdf. Accessed: 24. Apr. 2014
9. Ditterich, D., Engler, W., Bredau, J. (2011): Effizienter Drucklufteinsatz im Automobilbau, in: ATZproduktion 2011(4), pp. 2-7
10. Ecoinvent 2.2, http://db.ecoinvent.org/
11. St.Gallisch-Appenzellische Kraftwerke AG (2014): Broschüre Strompreise 2014. http://www.sak.ch/PortalData/1/Resources/01_sak_internet/de/24_e/05_strompreise_regelungen/Broschuere_Strompreise2014_SAK_Expert.pdf. Accessed 25. Apr. 2014
12. Saidur, R. et al. (2010): A review on compressed-air energy use and energy savings, in: Renewable and Sustainable Energy Reviews 2010(14), pp. 1135–1153
13. Radgen, P., Blaustein, E. (2001): Compressed air systems in the European Union. Germany: Energy, Emissions, Savings Potential and Policy Actions. http://www.isi.fraunhofer.de/isi-media/docs/isi-publ/2001/isi01b04/compressed-air-long.pdf. Accessed 25. Apr. 2014
14. ABB (2009): IEC 60034-30 Norm zu den Wirkungsgradklassen für Niederspannungsmotoren. http://www05.abb.com/global/scot/scot234.nsf/veritydisplay/36ef15c7594589a9c12578ab00264f67/$file/tm025%20de%20revb%202009_lowres.pdf. Accessed 25. Apr. 2014